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THE EFFECT OF LETTER POSITION ON RECOGNITION[1]

DOREEN KIMURA

McGill University

In a study by Mishkin and Forgays (3) it was found that if English words were tachistoscopically exposed either in the right visual field or in the left, more words were recognized in the right field than in the left. They suggested that, as a result of reading habits, "a more effective neural organization" for English words had been established in the left cerebral hemisphere than in the right.

A later experiment by Heron (2), however, demonstrated that the Mishkin-Forgays effect is only obtained when alphabetical material is exposed in one field at a time. If letters are exposed in both fields simultaneously, more letters are recognized to the left of fixation. Heron also found that when four letters arranged in a square are exposed either to the right or to the left of fixation, the accuracy with which the letters are recognized is a function of their position in the square: letters in the upper left corner of the square were recognized most frequently, then letters in the upper right, lower left, and lower right, in that order. Moreover, the order in which subjects reported them is the same. Heron pointed out that this effect could not be explained as a more effective neural organization in any one part of the brain since it occurred whether the letter square was in the right or the left visual field. His interpretation was in terms of an attentional process which operates as follows: when the stimulus is exposed, the traces corresponding to the exposed letters are excited; motor feedback from centres for eye movement facilitates each trace in turn, in the order in which the letters would normally be fixated while the subject was learning to read.

This interpretation raises several questions which may be answered empirically. (*a*) Is the response sequence the same over a wide range of stimuli, for example, when the letter square is presented with the fixation point at its centre, when gaps and non-alphabetical material are introduced, and when the space between the letters is changed? (*b*) What is the effect of reading experience? (*c*) Do changes in the duration of the

[1]This research was supported by grant 9401–11 to Dr. D. O. Hebb from the Defence Research Board, Ottawa. I wish to thank Dr. Woodburn Heron for his guidance throughout the investigation, and in the preparation of this paper.

stimulus affect the way in which letters are reported? This study is an attempt to answer these questions.

Method

The stimulus material consisted of 13 upper case letters and 8 geometric forms. These letters and forms were arranged in a square in the centre of 3″ × 5″ white cards so that the mid-point of each letter or form was equidistant from the fixation point. The recognition threshold of each letter had been previously determined, and the letters were rotated so that letters of equal difficulty appeared an equal number of times in each position. The geometric forms, which were slightly larger than the letters, were stencilled on the cards. Each form appeared in each position an equal number of times.

The subject was seated before a Gerbrands Harvard Tachistoscope. Before each exposure he was asked to fixate a dot in the pre-exposure field which corresponded to the fixation point on the stimulus cards. In all experiments a practice period, consisting of from 10 to 20 exposures, preceded each experimental session. After each exposure during the practice period, S simply reported orally what he had seen; during the experimental period he wrote his responses on paper. At no time was S informed whether his responses were correct or not. Rest periods were given at regular intervals and whenever requested.

In scoring the responses, the number of letters correctly recognized was computed for each of the 4 positions of the letter square. This yielded a measure of the relative frequency with which letters were recognized in these 4 positions.

Experiment I

The object of this experiment was to see whether the accuracy of recognition was affected by (*a*) using geometric forms and blank spaces in the letter series; (*b*) using geometric forms alone as stimuli; (*c*) increasing the horizontal distance between letters.

Subjects and Procedures

The Ss were 40 army personnel whose formal education, on the average, did not go beyond 8 years of schooling.

The stimulus material consisted of 24 different arrangements of letters and geometric forms. A diagram of some of these is given in Figure 1. In all types of stimuli, except groups 2 and 3, the horizontal distance between the letters (or forms) subtended a visual angle of approximately 1°56′, and the vertical distance an angle of 2°22′. In stimulus groups 2 and 3 the horizontal distance subtended angles of 4°26′ and 6°39′ respectively, but the vertical distance was unchanged, that is, the letters were no longer arranged in a square, but in a rectangle. In groups 4 to 7 one letter from each group was omitted, and in groups 8 to 13 two letters were omitted. The positions in which the letters were omitted were rotated, so that the gaps occurred an equal number of times in each part of the square. Group 14 consisted entirely of geometric forms. In groups 15 to 18 one geometric form was introduced into the letter series; in groups 19 to 24 two forms were introduced. The position of the forms was again rotated so that they occurred an equal number of times in each position.

There were 8 examples of each of the 24 stimulus groups, making a total of 192

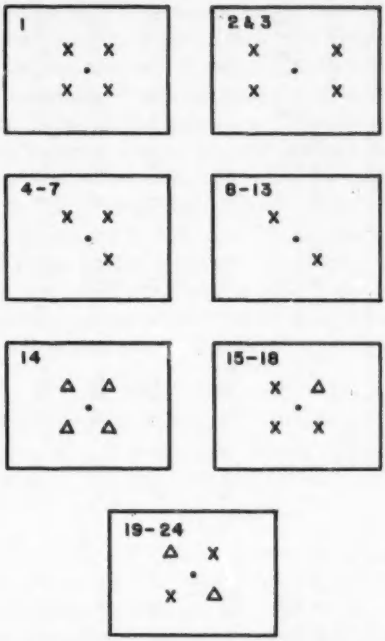

FIGURE 1. Samples of stimulus groups used in Experiments I and II. X represents a letter, △ a geometric form.

cards. These cards were presented in a pre-determined random order for a period of 30 milliseconds each.

RESULTS

The results are summarized in Table I. The data from stimulus group 1, which is similar to that used by Heron (though his letter squares were presented either to the right or to the left of fixation), indicate that even with the fixation point in the centre of the square of letters, the recognition scores for the four positions yield the same order as that which he found: that is, the order of recognition is from upper left to lower right. The difference between the two upper positions is not significant, but letters in the top positions are recognized significantly more often than letters in the bottom positions, and those in the lower left better than those in the lower right.

The recognition scores for the groups of geometric forms (stimulus group 14) and for letters with geometric forms added (stimulus groups

TABLE I

MEAN NUMBER OF STIMULUS OBJECTS REPORTED BY SOLDIERS

Stimulus groups	Maximum score	Position				*t* values						Order of report
		UL	UR	LL	LR	UL & UR	UR & LL	LL & LR	UL & LL	UL & LR	UR & LR	
Letter group: visual angle 1′ 56″(1)	8	3.13	3.1	2.05	1.53	.00	3.09**	2.21*	2.84**	4.32**	4.79**	UL UR LL LR
Letter groups: angles 4′ 26″ & 6′ 39″ (2 & 3)	16	4.23	5.15	1.45	3.28	2.03*	6.6**	5.59**	4.56**	1.14	3.4**	UR UL LR LL
Letter groups with gaps (4–13)	48	24.78	26.38	19.35	19.9	1.67	3.48**	.55	2.65*	2.21*	3.00**	UR UL LR LL
Group of forms: visual angle 1′ 56″ (14)	8	2.38	2.18	1.15	.98	.71	3.03**	.69	3.24*	5.00**	4.04**	UL UR LL LR
Groups with geometric forms (15–24)	80	31.03	30.75	17.75	15.7	.19	3.51**	1.51	3.49**	3.83**	4.07**	UL UR LL LR

*Significant at the 5 per cent level of confidence.
**Significant at the 1 per cent level of confidence.

UL—Upper Left
UR—Upper Right
LL—Lower Left
LR—Lower Right

15 to 24) are in the same order (upper left to lower right). Thus, there seems to be a general tendency for both letters and geometric forms to be recognized in the order in which letters would normally be read.

However, under certain conditions, this order is changed. When the horizontal distance between the letters is increased (stimulus groups 2 and 3), significantly more letters are recognized to the right of the fixation point than to the left: that is, the order of recognition is now upper right, upper left, lower right, lower left. When gaps are present in the stimuli (groups 4 to 13), some disruption of the normal order also occurs since more letters are now recognized in the upper right than in the upper left position. There is still some tendency, however, for the normal ordering process to operate since in all these examples more letters are recognized above the fixation point than below it.

Experiment II

In the second experiment, designed to test the effect of reading experience, the same stimuli were given under conditions identical with those of Experiment I. The subjects were twenty college students.

Results

The summary in Table II indicates that the results are similar to those obtained in Experiment I. Again, the top letters are more easily recognized than the bottom, and an increase in the horizontal distance between the letters results in greater frequency of recognition in the right visual field.

When we consider the stimulus groups in which gaps are introduced, however, we find that, in contrast to the results of Experiment I, letters in the upper left are recognized as well as those in the upper right position. With letter groups containing forms (15–24), the upper left is significantly better than the upper right. In other words, the introduction of gaps or forms is not as disruptive of the order of recognition for the students as it is for the soldiers.

Experiment III

The length of time that the stimuli are exposed has varied greatly from one experimenter to another, and this factor has never been studied. The kind of "post-exposural process" postulated by Heron, however, implies that discrimination of the stimulus arrangement must take place before the selective mechanism operates. Presumably, then, if the stimulus is of short duration, the post-exposure process may not operate, that is, there will be no selective recognition. The relation between duration of stimulus and the effect of letter position on recognition is studied in this experiment.

TABLE II

MEAN NUMBER OF STIMULUS OBJECTS REPORTED BY STUDENTS

Stimulus groups	Maximum score	Position				*t* values						Order of report
		UL	UR	LL	LR	UL & UR	UR & LL	LL & LR	UL & LL	UL & LR	UR & LR	
Letter group: visual angle 1′ 56″ (1)	8	5.05	4.8	3.7	2.8	.73	2.17*	2.97*	2.55*	5.23**	3.98**	UL UR LL LR
Letter groups: angles 4′ 26″ & 6′ 39″ (2 & 3)	16	7.4	8.45	4.05	5.15	2.16*	5.25**	1.54	4.21**	2.53*	3.99**	UR UL LR LL
Letter groups with gaps (4–13)	48	33.8	33.65	28.1	28.45	.21	3.6**	.32	4.07**	3.09**	2.57*	UL UR LR LL
Group of forms: visual angle 1′ 56″ (14)	8	3.45	3.85	2.05	1.15	1.21	3.39**	2.57*	3.18**	4.41**	5.29**	UR UL LL LR
Groups with geometric forms (15–24)	80	46.95	42.8	28.9	22.15	2.75*	3.2**	3.5**	4.59**	5.37**	4.54**	UL UR LL LR

*Significant at the 5 per cent level of confidence.
**Significant at the 1 per cent level of confidence.

UL—Upper Left
UR—Upper Right
LL—Lower Left
LR—Lower Right

Subjects and Procedure

Fifty-six cards containing alphabetical material only were presented to college students. In order to simplify the situation, the stimuli used were similar to stimulus groups 2 and 3 (see Figure 1) of the first two experiments. The position scores of these stimulus groups had yielded a reliable difference between left and right (in favour of the right) for both educational levels. It was thus felt that if any effect of exposure time could be found using these stimuli, it would have greater validity than if some of the other stimulus groups were used.

There were two groups of subjects. One group (N=11) was presented with the stimulus cards for a period of 20 msec. each, the other (N=12) for a period of 40 msec. each.

Results

Since the differences between positions are not significant for either group of subjects, the position scores are not given in tabular form. As was expected, however, there is a tendency for the upper scores to be higher than the lower, and for the right to be better than the left *in the 40-millisecond condition*. This is not so in the 20-millisecond condition.

Since the right-left differences have been of most interest in other studies of this kind, it was decided to combine the scores for the two left and right positions. Comparisons of the total left and right scores is made in Table III. The t ratio of the difference between left and right

TABLE III

Mean Number of Letters Reported under Two Conditions (Maximum, 112)

Condition	Right	Left	Difference
40-msec. duration	61.9	46.5	15.4*
20-msec. duration	24.5	25.2	.64

*$P < .05$, Wilcoxon signed-ranks test.

under the 40-millisecond condition is 2.04, which is not significant with 11 degrees of freedom. With this type of task, there is great variability in the magnitude of the difference. The Wilcoxon matched-pairs signed-ranks test (4) was therefore applied to the data in order to take account of the direction as well as the size of the difference. With this test the difference between left and right under the 40-millisecond condition is significant at the 5 per cent level of confidence. The difference between left and right for the 20-millisecond condition is not significant with either test.

It appears, then, that the effect of letter position on recognition changes with exposure time. The data from the above study suggest that, with very short exposure times, the effect may disappear altogether.

Discussion

Heron (2), in his explanation of the effects of letter position on recognition, has suggested that the excitation of a trace produced by a brief stimulation is followed by additional facilitation. This facilitation is assumed to come primarily from centres for eye movement and to be sequential in nature, that is, each trace, in turn, receives enough facilitation to make possible a response, the order of these responses being determined by eye movements made during the development of reading ability. Essentially, this is a feedback mechanism.

The present results are not entirely compatible with Heron's interpretation. In the first place, letters are reported from upper left to lower right only when the letter groups are arranged in the form of a square. Under other conditions, the right seems superior. A second unexpected finding is that geometric forms are reported in the same order as a corresponding group of letters. The first result indicates that the ordering phenomenon is not as stable as Heron's interpretation would suggest, and the second that it is not specific to alphabetical material.

The assumption that ordering takes place through the sequential facilitation of one trace by another (via eye movement centres) runs into difficulty with the data on letter groups with wider spacing. The order of recognition for these two stimulus groups (2 and 3) was upper right, upper left, lower right, and lower left. Since no eye movement of this upper-right-to-lower-left kind is normally made in reading, there should presumably be no facilitation available in this order.

On the other hand, some of the results do support Heron's hypothesis. There is a strong tendency to recognize letters in the upper positions more frequently than those in the lower positions, a difference which is apparent under almost all conditions. Furthermore, the introduction of gaps and geometric forms seems to have a more disruptive effect with subjects who have had relatively little reading experience than with subjects who have had a great deal.

These results suggest that there is more than one attentional habit operating when the stimuli are presented. The stable upper-left-lower-right order is obtained only under certain conditions. Whenever this order is disrupted, letters to the right of fixation are recognized more often than those to the left. We are left with the problem of establishing the origin and relative strengths of these conflicting tendencies.

Forgays (1), in an experiment with school children, found that with successive presentation of letters to either side of the fixation point, children in the lower grades showed, if anything, slightly better recognition on the left, whereas children above Grade 7 showed significantly better recognition on the right. It is probable, then, that there is a strong

tendency in all people with some reading experience (in English) to attend to material to the right of fixation. This is consistent with the data of the present study.

It is also probable that as more facility is being gained in reading, an attentional habit of greater complexity than this is being developed. This is the tendency to attend to alphabetical material from left to right, or from upper left to lower right. This later habit would not necessarily supersede the first tendency to attend to the right: it would merely operate under a more limited set of conditions. When letter groups with wider spacing, or with gaps and forms are used, these conditions would not be fulfilled. Consequently, the habit of attending to the right would be dominant.

This is the explanation which seems to fit the data best at this stage. It is clear, at least, that the final explanation must be in terms of a combination of tendencies, an interpretation hard to reconcile with a motor feedback mechanism, unless we allow of more than one feedback pattern operating at one time. Heron, indeed, has suggested a combination of two major tendencies in eye movement to account for the difference between conditions of successive and simultaneous exposure. It is difficult, however, to conceive of conflicting patterns of sequential facilitation from one trace to another, and to attempt such an extension of his proposed mechanism would perhaps complicate the problem unnecessarily.

An alternative to the hypothesis of sequential facilitation is that the amount of facilitation that each trace receives is important in determining the accuracy with which the corresponding letter is reported. That is, where the upper left letter, for example, is reported most frequently, it may be due, not to the fact that it is the position facilitated first, but to the fact that it receives the greatest total amount of facilitation. The source of this facilitation must be some combination of habits acquired through reading experience, these habits acting in an additive way to determine the amount of facilitation for any one position. Whether any part of this facilitation is mediated by centres for eye movement is still a question, but it cannot be the complete explanation.

Summary

Twenty-four different arrangements of letters and geometric forms were presented tachistoscopically to two groups of subjects differing in educational level. The accuracy with which letters in each of four positions were recognized varied with the arrangement of the stimuli and with the reading experience of the subjects. In a further study the duration of the stimulus was found to be an additional factor in determining the order in which letters were recognized.

These results indicate that perception of this type of material is not a sole function

of either retinal locus or eye movement tendencies. It is suggested, instead, that the explanation must be some *combination* of habits acquired during reading.

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RECOGNITION OF SYMMETRICAL AND NON-SYMMETRICAL INK-BLOTS WITH AND WITHOUT EYE MOVEMENTS[1]

CRAIG M. MOONEY

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PRESUMABLY THE RECOGNITION of novel visual configurations on the occasion of a second experience with them exemplifies a simple kind of perceptual learning. In a previous study (1) the question of the relative efficacy, in such learning, of two methods of observation—a single brief glance, and a period of visual inspection—was tested; and an attempt was made to reveal the advantage that might accrue to one or the other method with two kinds of novel configurations—structured and amorphous. The findings revealed a high level of performance that was maximal by either method of observation with either kind of configuration.

It was tentatively concluded that this kind of performance entailed a primitive form of perceptual learning in which the single glance was sufficient and visual inspection was superfluous. It was presumed that this was because both the structured and the amorphous configurations afforded no grounds for cognitive associations and were notable only by virtue of their idiomatic states—for which the single glance was adequate.

The present study is based on the proposition that, although visual inspection is not essential for providing the memories that permit these simple "second occasion" recognitions, it should prove superior to the single brief glance with configurations so constituted in whole or part as to suggest meanings or rouse associations that might perform a mnemonic service. The explicit reasoning is this: given novel visual configurations which might be presumed to be especially amenable to a constructive, associative process, and assuming (i) that such a process would operate to make the configurations more memorable, and (ii) that it would gain in *effect* over time, it would follow that the memorability of the configurations would be significantly enhanced when observed by the method of visual inspection rather than the single brief glance.

Black-and-white ink-blots commended themselves as the appropriate

[1]Defence Research Medical Laboratories Report no. 142–2, Project no. D77–94–35–29 (H.R. no. 162).

configurations by virtue of their ambiguously suggestive or quasi-meaningful character. With this choice, the possibility could not be overlooked that symmetrical ink-blots might be more evocative of associations than non-symmetrical ones. The undertaking to present a series of configurations afforded opportunity to vary the intervals between the initial appearance and the subsequent reappearance of any configuration in terms of the number of intervening perceptual occasions (involving presentation of *other* configurations). The additional degrees of freedom afforded by these latter factors promised a more rigorous test of the foregoing proposition, and were, accordingly, incorporated into the present experiment.

Method

Apparatus

In this experiment, 16 symmetrical and 16 non-symmetrical ink-blots were created and mounted on 35-mm. slides. Examples are shown in Figure 1. They constituted, respectively, two separate series. The 16 items in each series were

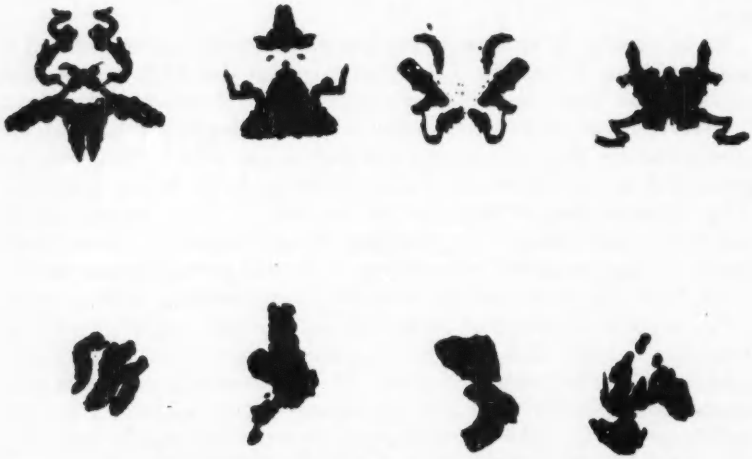

Figure 1. Examples of symmetrical and non-symmetrical ink-blots.

arranged for a sequence of 32 presentations—based on an initial and subsequent presentation of each item—in such a manner that the sequence would not be foreseen by Ss. Each sequence was so designed that 4 of the ink-blots occurred with 1 other ink-blot interposed between initial and subsequent appearance, 4 occurred with 2 other ink-blots so interposed, 4 occurred with 3 interposed, and 4 with 4 interposed, with the further restriction that each quarter of the sequence would encompass 4 initial and 4 subsequent appearances.

A projector, in a dark-room, with a variable speed light-interrupter in the beam (light-dark ratio 50:50), permitted projection of the ink-blots onto a square white screen 2 ft. wide, 6 ft. in front of S, for either brief or lengthy periods.

Subjects

The subjects were young males, ranging in age from 18 to 25 years, applying for enlistment at an army recruiting centre. They were informed that the tests were a measure of their visual speed and memory and were permitted to assume that they were an integral part of the routine examination for military fitness.

Design

The subjects were tested twice: with one series, where they were afforded a single brief glance at each ink-blot, and with the second series, where they were permitted to inspect each ink-blot. A factorial design was employed, accounting for the variables: series (symmetrical *vs.* non-symmetrical), exposure (single glance *vs.* period of visual inspection), and series order (first test *vs.* second). In all, 24 Ss were used, permitting 6 replications.

Procedure

The subject saw the ink-blots in one series exposed for .07 sec. and those in the other series for 5 sec. The .07-sec. exposure (one-fifteenth sec.) was chosen because, being faster than one-tenth sec., it eliminated the possibility of the eye making a second movement. To anticipate a .07-sec. exposure S fixated the centre of a square area on the screen illuminated by successive .07-sec. flashes of light occurring at 1-sec. intervals—where, after approximately 10 flashes, the ink-blot would suddenly appear and disappear. While the intervening flashes of light employed with the .07-sec. exposure were intended not only to centralize fixations but to suppress subsequent after-images, the occurrence of these latter could not be eliminated as a factor; however, since after-images cannot be visually scanned and would be seen from the same fixed point of regard as the original displays, their occurrence would not alter the fact that at the .07-sec. exposure configurations were observed with but one fixation as against the multiple fixations possible during the 5-sec. exposure. For the 5-sec. exposure S fixated the centre of the same square steadily illuminated —where, at about 10-sec. intervals, the ink-blots would appear for 5 sec. Each test took about 10 min., with a recess of 5 min. between.

The subject was told that he would be viewing meaningless shapes each of which would appear a first time and reappear sooner or later in a long sequence of such presentations; that he was to "look hard" at each one as it appeared in order to be able to recognize it later; that he was to indicate this by calling "Yes" or "No" each time a shape was presented, starting with the first one in the series; that by "Yes" he would mean it was one he recognized having seen before, and by "No" that it was one he had not seen before.

Scoring was in terms of errors. An erroneous "No" response (that is, a failure to recognize an ink-blot on its second appearance) counted as a non-recognition; an erroneous "Yes" (erroneously "recognizing" an ink-blot on its first appearance) counted as a false recognition. The right-minus-wrong scoring convention was not employed since there seemed to be no logical warrant for *a priori* assumptions that a failure to recognize a previously seen configuration was equivalent to a false recognition of one not previously seen, or that so-called guessing was simply guessing, or was equally likely with both initial and subsequent presentations.

Results

Performance, in terms of the two methods of viewing and the two kinds of ink-blots, is shown in Table I, with the analyses of variance presented in Table II. The method of exposure employed was the major source of differences in performance. It was the sole differentiating factor for false recognitions; these amounted to 8.6 per cent at the 5-sec. exposure, and to 18.5 per cent at the .07-sec. exposure; the symmetry or non-symmetry of the ink-blots was of no consequence, and there was no effect attributable to series order. Non-recognitions amounted to 12.6 per cent with the 5-sec. exposure, and to 25 per cent with the .07-sec.

TABLE I

Non-recognitions (Failure on Second Appearance) and False Recognitions (Error on First Appearance) of Ink-blots with and without Eye Movements

Exposure (sec.)	Series order	Ink-blot series: Non-symmetrical Non-rec.	Non-symmetrical False	Symmetrical Non-rec.	Symmetrical False	Total Non-rec.	Total False
.07	1st	36*	20*	27	11	63	31
	2nd	21	17	12	23	33	40
	TOTAL	57	37	39	34	96	71
5	1st	13	9	12	6	25	15
	2nd	7	13	17	5	24	18
	TOTAL	20	22	29	11	49	33
Totals	1st	49	29	39	17	88	46
	2nd	28	30	29	28	57	58
	TOTAL	77	59	68	45	145	104

*Total possible error-score per entry: 96—based on 6 different *Ss* tested with 16 ink-blots under each experimental condition.

TABLE II

Analysis of Variance for Non-recognition and False Recognition of Ink-blots

Source	df	Non-recognitions MS	Non-recognitions *F*	False recognitions MS	False recognitions *F*
Series order (O)	1	20.02	10.59*	3.00	
Series (S)	1	1.70		4.08	
Exposures (E)	1	46.02	24.35**	30.07	10.92*
O×S	1	2.51		2.08	
O×E	1	17.52	9.27*	.76	
S×E	1	15.18	8.03*	1.34	
O×S×E	1	2.46		8.32	
Cells	40	1.89		2.76	
Totals	47	180.90		160.67	

*$p = .01$ **$p = .001$.

exposure. However, this finding has to be interpreted in the light of an interaction between exposure and series, and an interaction between exposure and series order. Thus, at the 5-sec. exposure, 10 per cent of the non-symmetrical ink-blots were missed, and 15 per cent of the symmetrical; and at the .07-sec. exposure, 30 per cent of the non-symmetrical ink-blots were missed, and 20 per cent of the symmetrical; and, for the interaction between exposure and series order, the major source of variance was the 33 per cent missed at the .07-sec. exposure on the first series encountered. Figures 2 and 3 depict these relations.

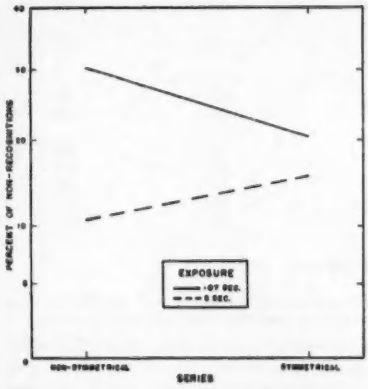

FIGURE 2. Non-recognitions of ink-blots in terms of series order and exposures.

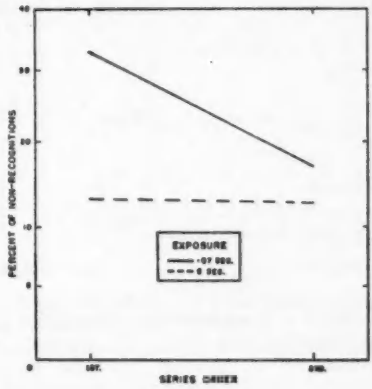

FIGURE 3. Non-recognitions of non-symmetrical and symmetrical ink-blots in terms of exposures employed.

The following supplementary findings take account of the fact that in each series the ink-blots were presented with one, two, three, and four other ink-blots interposed between initial and subsequent appearance, and of the further fact that in each quarter of each series there were four initial and four subsequent appearances. Thus, the error-scores can be further broken down for exposure, series, and interpositions, as shown in Table III; and they can also be broken down for exposure, series, and quarter-series, as shown in Table IV. The former breakdown reveals a significant (.01 level) second-order interaction (and the only one—as tested by an analysis of variance supplementary to that shown in Table II—involving interpositions as a fourth variable); the major source of variance is due to the increase of errors with the non-symmetrical ink-blots at the .07-sec. exposure coincident with increasing interpositions. The latter breakdown (Table IV) reveals a marked difference in the trend of the two kinds of responses through the series, and it is evident

TABLE III

NON-RECOGNITIONS OF INK-BLOTS WITH AND WITHOUT EYE MOVEMENTS IN TERMS OF THE NUMBER OF OTHER INK-BLOTS INTERPOSED BETWEEN THEIR INITIAL AND SUBSEQUENT APPEARANCES

Exposure (sec.)	Number of interpositions	Ink-blot series: Non-symmetrical	Symmetrical	Total
.07	1	7	9	16
	2	12	8	20
	3	14	7	21
	4	24	15	39
	TOTAL	57	39	96
5	1	7	3	10
	2	5	7	12
	3	3	4	7
	4	5	15	20
	TOTAL	20	29	49
TOTALS	1	14	12	26
	2	17	15	32
	3	17	11	28
	4	29	30	59
	TOTAL	77	68	145

TABLE IV

NON-RECOGNITIONS AND FALSE RECOGNITIONS OF INK-BLOTS WITH AND WITHOUT EYE MOVEMENTS FOR SUCCESSIVE QUARTERS OF THE TEST SERIES

Exposure (sec.)	Quarter	Ink-blot series: All non-symmetrical Non-rec.	False	All symmetrical Non-rec.	False	Total Non-rec.	False
.07	1st	22	1	19	6	41	7
	2nd	17	16	11	8	28	24
	3rd	9	11	6	11	15	22
	4th	9	9	3	9	12	18
	TOTAL	57	37	39	34	96	71
5	1st	6	2	15	3	21	5
	2nd	5	5	8	1	13	6
	3rd	4	10	5	2	9	12
	4th	5	5	1	5	6	10
	TOTAL	20	22	29	11	49	33
TOTALS	1st	28	3	34	9	62	12
	2nd	22	21	19	9	41	30
	3rd	13	21	11	13	24	34
	4th	14	14	4	14	18	28
	TOTAL	77	59	68	45	145	104

by inspection that these trends are unaffected by the nature of the series, series order, or exposure. "No" responses predominate in the first quarter of the series and are markedly successful, while the fewer "Yes"

responses are highly erroneous; the two categories come together midway in the series; and in the last quarter the "Yes" responses predominate and are mostly correct, while the lesser number of "No" responses are more erroneous. These relations are shown in Figures 4 and 5.

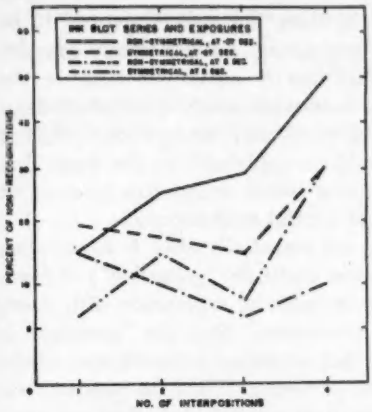

FIGURE 4. Non-recognitions of non-symmetrical and symmetrical ink-blots, in terms of exposures and interpositions between initial and subsequent appearance.

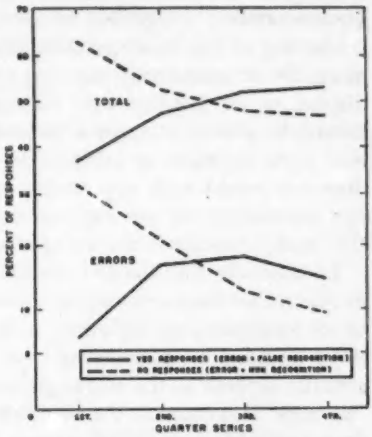

FIGURE 5. Total responses in terms of non-recognitions and false recognitions for successive quarters of the testing series.

In short, the differences in results between the two methods are not great, even where they are significant, nor are they consistent. Visual inspection has a slight advantage in minimizing false recognitions regardless of the factors of symmetry or order. Its advantage in minimizing non-recognitions is evident only with non-symmetrical ink-blots, or on the first test occasion.

DISCUSSION

It is clear that visual inspection is not essential in laying down the memories upon which these simple recognitions are based, nor is it markedly and consistently superior to the single brief glance. The high level of accomplishment with the single brief glance under all circumstances, and the relatively small and limited gains with the method of visual inspection, suggest that the two methods are not intrinsically different. It appears more likely that the differences in performance are due to extrinsic factors incidental to the experimental management of the two methods or to differing subjective reactions to them. Intermittent

flashing and sudden exposure entailed in the single brief presentation are factors not present in the usual method of visual inspection.

The following might be the simplest line of reasoning. If the method of visual inspection were essentially different from that of the single brief glance, it would be because eye movements support a visual (neurocortical) integration of part-views, or, at least, a reinforcing or rehearsing of the multi-part display. If, then, the method proved to be markedly or consistently superior in "imprinting" an elaborately complex display or an implicatively structured one it would be because the attendant visual integrative process facilitated central redintegrations that were requisite or relevant to the perceptual recognitions. That it does not reveal such superiority, could be explained on the basis that eye movements do not support any such visual integrative process, or that such a process is not an agency of central redintegration.

To conclude that the two methods are essentially alike is to propose, in effect, that the memorability (however cortically "grounded") of these novel configurations, following a first occasion of experience with them, owes nothing to inspectional eye movements; that the "memory" is actually secured in the single glance; that whatever is constitutive of the "memory" is secured in the first instant of seeing. While the present data do not provide unqualified support for such a conclusion, they are more consistent with it than with any other.

Summary

The present experiment was based on the proposition that the memorability (measured by subsequent recognizability) of novel visual configurations would be more effectively ensured by visual inspection than by a single brief glance—on the logical thesis that a visual summative process would be possible by virtue of eye movements; that this would more effectively subserve central associative processes; and that this would make the configurations more memorable.

The experiment was of factorial design, replicated six times. Each of 24 Ss was tested twice at one sitting, employing two series of ink-blots, 16 symmetrical and 16 non-symmetrical, one test entailing presentation of one series at a .07-sec. exposure, the other test entailing presentation of the other series at a 5-sec. exposure. During the 32 presentations (16 initial and 16 subsequent appearances) entailed in each test S was required to "memorize" each ink-blot as it appeared, and at each presentation to state "Yes" (for "Seen before") or "No" (for "Not seen before"). Scoring was based on two kinds of errors, non-recognitions and false recognitions, and these were separately analysed.

Visual inspection proved to be only slightly more advantageous than the single brief glance—equally so for both symmetrical and non-symmetrical ink-blots—in minimizing false recognitions. Its advantage was not established in guarding against non-recognitions. It revealed a slight, but significant, superiority only with non-symmetrical ink-blots, or only on the first of the two test occasions. With symmetrical ink-blots, or on the second test occasion, it was no more effective than the single brief glance.

The findings did not warrant the conclusion that visual inspection possesses any real advantage over the single brief glance in providing the "memories" for these novel configurations. The slight differences in favour of visual inspection could be attributed to factors associated with the experimental management of the two methods. The reasonable conclusion seemed to be that eye movements involved in the act of visual inspection, and any postulated consequent processes of visuo-cortical redintegration, were either non-existent or irrelevant, and that, by both methods, the "memories" were secured in the first instant of seeing.

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THE FOREPERIOD AND SIMPLE REACTION TIME[1]

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THE FOREPERIOD in simple reaction time has in the past been defined as the interval between the termination of ready signal and the onset of the stimulus. The duration of the foreperiod so defined which results in the fastest reaction times is not too well established. Woodrow (3), using an auditory ready signal and stimulus, reported 2 to 4 seconds to be optimum. Freeman and Kendall (1), using a tension-producing movement of the forearm as a ready signal and an auditory stimulus, placed the optimum between 4 and 8 seconds. They also point out that "when a systematic attempt is made to control the locus and amount of anticipatory tension, all subjects tended to show an optimal preparatory interval at 8 seconds." Telford (2) found that a 1- or 2-second foreperiod was significantly better than one of 0.5 or 4 seconds. He used no ready signal, his intervals being measured from the cessation of the preceding stimulus, an auditory one.

The differences in procedure and findings in these experiments suggest a relation between the ready signal itself and the optimum duration of the foreperiod. Accordingly the present experiment was undertaken to investigate the possible relation. Specifically, the following questions were asked: (1) In obtaining the shortest reaction time, is the duration of the ready signal itself related to the duration of the foreperiod? (2) Does the effective foreperiod start with the onset of the ready signal, or with its cessation?

METHOD

Apparatus

The subject's display was a black board, normal to his line of sight on which were mounted two small lights, one above the other. The top light, red in colour, was the ready signal, and the bottom light, green, was the stimulus. The brightness of these lights was approximately 100 ft. lamberts. Mounted directly beneath the board was a microswitch, the response key. Reaction times were measured using a "Standard" clock calibrated in hundredths of a second.

The apparatus consisted of three Hunter timers, a stepping switch, and a series of relays arranged so that (*a*) the duration of the ready signal, (*b*) the duration of

[1]Defence Research Medical Laboratories Project no. 107, DRML Report no. 107–4, PCC no. D77–94–20–23 (H.R. no. 159).

the foreperiod, and (*c*) the interval between S's response and the onset of the next ready signal were independently variable.

Procedure

Let T denote the interval between the onset of the ready signal and the onset of the stimulus. Let t_1 denote the duration of the ready signal, and t_2 denote the interval between the cessation of the ready signal and the onset of the stimulus. Therefore, $T = t_1 + t_2$.

In the experiment t_1 was varied so that the ratio t_1/T assumed the values of 1:4, 2:4 and 3:4 for each value of T. Three values of T were used, 2, 4, and 8 sec. Thus when T was 2 sec., t_1 was 0.5, 1.0, or 1.5 sec., etc.

The stimulus went out when S pressed the response key. The interval between S's response and the onset of the next warning light was 4 sec. In all 20 consecutive presentations were made to each S under each condition, the first 10 being considered practice trials. The analysis is based on the last 10.

The design used was a 3 × 3 factorial. The 9 possible conditions of T and ratio (R) were presented to each S in random order during one session.

In all, 8 subjects were used, 6 male and 2 female, ranging in age from 20 to 40 years. Subjects were instructed to respond to the onset of the stimulus light, by pressing the response key as quickly as possible. Each was allowed to use his or her preferred hand, the responding finger, the index finger, resting on the board in front of the key until the onset of the stimulus light.

Results

The means of the reaction times for each condition are shown in Table I. An analysis of variance was carried out. The results are shown in Table II.

The results permit the following conclusions to be drawn. (1) The effect of varying the ratio t_1/T is not significant within the values studied. Therefore, the relative duration of t_1 with respect to T is not a factor in determining an optimum. (2) Differences in T are significant. The interaction between T and t_1/T is not significant. Subject interactions are not significant. Therefore, the effective foreperiod starts with the onset of the ready signal. Further, an effective foreperiod of 2 seconds results in significantly faster reaction times than an effective foreperiod of 4 or 8 seconds.

TABLE I

Mean Reaction Times, in 1/100ths sec., for Each Ratio t_1/T and for Each Value of T, where t_1 is Duration of Ready Signal and T is Interval from Onset of Ready Signal to Onset of Stimulus

	T (sec.)		
t_1/T	2	4	8
1:4	25.03	27.80	28.17
2:4	25.93	26.93	27.53
3:4	26.52	27.05	28.21
Totals	25.83	27.26	27.97

TABLE II

ANALYSIS OF VARIANCE

Source	df	SS	MS
Subjects (*S*)	7	27919.187	3988.455
Ratios (*R*)	2	25.344	12.672
T			
4 sec. *vs.* 8 sec.	1	60.919	60.919
2 sec. *vs.* 4 and 8 sec.	1	510.534	510.534
T×*R*	4	122.664	30.666
S×*R*	14	660.834	47.202
S×*T*	14	650.492	46.463
S×*R*×*T*	28	757.625	27.058
Within cells	648	8287.500	12.789

DISCUSSION

The fact that an effective foreperiod starts with the onset of the ready signal may explain some of the discrepancies in optimum foreperiod reported by various investigators. The foreperiod has not normally been defined as including the ready signal. Therefore the reported foreperiods should include the ready signal, to arrive at the effective foreperiods.

It may also be surmised that the type of ready signal is important since the onset appears to act as a triggering mechanism. A ready signal stimulating one sense modality may have differing effects upon reaction time when the stimulus signal affects another sense modality, as in the Freeman and Kendall experiments.

Further, when the preceding stimulus is used as a ready signal, as in Telford's investigation, the triggering action of the onset of the ready signal may be so confounded with the action of responding as to change the situation completely, making comparisons inappropriate.

SUMMARY

An experiment was undertaken to answer the following questions. (1) In obtaining the shortest reaction time, is the duration of the ready signal itself related to the duration of the foreperiod? (2) Does the effective foreperiod start with the onset of the ready signal, or with its cessation? It was concluded that relative duration has no effect, but that the effective foreperiod starts with the onset of the ready signal. The relevance of these conclusions to the discrepancies in optimum foreperiod length reported in the literature is discussed.

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A COMPARISON OF TACTUAL AND VISUAL INTERPOLATION[1]

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SCALE INTERPOLATION is typically studied as a task which involves visual perception. Interpolation studies usually entail the presentation of a visual display consisting of two or more terminal reference marks, that is, one or more scale intervals, and an index marker in the form of a pointer. The general procedure is to have the subject estimate the position of the marker between adjacent reference marks, usually requiring interpolation to tenths of the scale interval.

The present experiment was conducted to investigate the effect of the sense modality employed, that is, tactual versus visual, on scale interpolation. Subjects were required to interpolate: (*a*) tactually and (*b*) visually, to tenths of a scale interval, the "reference marks" of the interval being two brass rods differing in diameter. The nine intermediate positions of the "marker," one through nine, were represented by rods having diameters between those of the two reference rods.

METHOD

Apparatus

The scale consisted of 11 rods ranging from ½ to 1⅛ in. in diameter, in 1/16 in. increments. The reference marks, that is, the ½ and 1⅛ in. rods, were vertically mounted in a frame in such a manner that *S* could grasp the rods between thumb and forefinger. These reference rods were designated as "zero" and "ten" respectively. The "zero" rod was mounted 12 in. to the left of the "ten" rod. The rods were secured at both ends, and were 1¾ in. in length.

The 9 positions of the index were represented by the 9 intermediate rods, that is, position one (1/10th) was represented by a rod 9/16 in. in diameter, position two by a rod 5/8 in. in diameter. The intermediate rods were vertically mounted around the perimeter of a turntable. Rotation of the turntable permitted the presentation of any one of the intermediate rods at a point midway between the two reference rods.

Under the condition of tactual interpolation the apparatus was screened from *S*'s view by a drop-cloth which also covered *S*'s hands. Under the condition of visual interpolation the drop-cloth was replaced by a panel with a 1¾ × 1¾ in. aperture in front of each of the reference rods and the position occupied by the intermediate rods. The middle aperture was equipped with a shutter to prevent *S* viewing the various rods while they were being rotated into position.

[1]DRB Project no. 164; Rep. no. 164–9; PCC no. D77–94–20–27; H.R. no. 170.

Procedure

Ten laboratory personnel served as Ss. For tactual interpolation S was seated in front of the apparatus with his hands covered by a drop-cloth. In this position S could comfortably grasp the ½-in. rod between the thumb and forefinger of his left hand, and the 1⅛-in. rod between the thumb and forefinger of his right hand. The location of the intermediate rod midway between the two reference rods permitted S to grasp the intermediate rod with either hand. In general, Ss tended to compare the rod to be judged with each reference rod in turn, that is, grasping it with the right hand to compare it with "zero," and then with the left hand to compare it with "ten." (It is to be noted that Kelvin (1) has shown that size is judged equally well with either hand.) Each of the 9 intermediate rods was presented 6 times in a random series of 54 presentations.

The apparatus was then modified to permit visual interpolation, the visual study being conducted on the same Ss one week later. Under visual conditions the viewing distance was 28 in.

In both situations the S's task was to report the fraction of the interval represented by the intermediate rod presented, that is, "four" for the intermediate rod representing four-tenths of the interval. Subjects were restricted to 9 different responses, from "one" to "nine" inclusive.

Results

Errors of interpolation were tabulated in terms of frequency and magnitude, and were classified as errors of overestimation, that is, positive errors, or errors of underestimation, that is, negative errors. Since consideration of error magnitude does not alter the main results, only error frequencies are discussed here.

Figure 1 shows the percentages of stimuli overestimated and underestimated by ten subjects for both tactual and visual interpolation.

From the mean row of Figure 1 it is seen that 55.9 per cent of the tactual interpolations were in error, of which 15.7 per cent were overestimations and 40.2 per cent were underestimations. Of the visual inter-

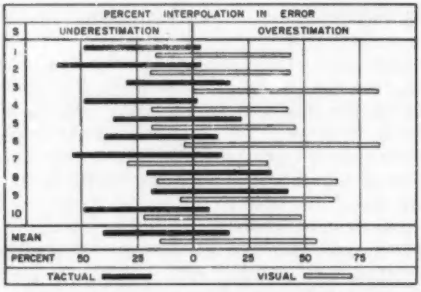

Figure 1. Percentages of overestimations and underestimations for tactual and visual interpolation, 10 subjects.

polations, 70.4 per cent were in error, 55.4 per cent being overestimations and 15.0 per cent underestimations. Eight of the ten subjects made more errors of underestimation than overestimation for tactual interpolation, and all ten subjects made more errors of overestimation than underestimation for visual interpolation. It is also apparent that tactual underestimations exceeded visual underestimations, and that visual overestimations exceeded tactual overestimations, for all ten subjects. The significance of these differences is apparent by inspection.

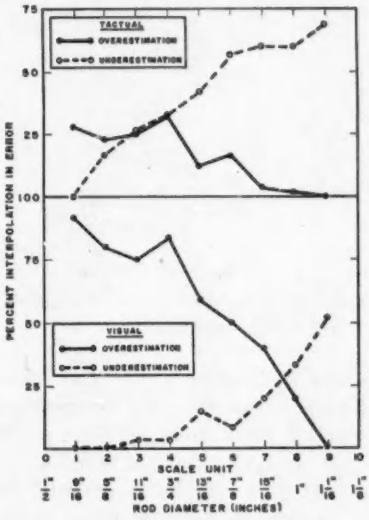

FIGURE 2. Percentages of overestimations and underestimations on each of 9 intermediate rod positions for tactual and visual interpolation.

Figure 2 shows the percentages of overestimations and underestimations for tactual and visual interpolation at each of the nine intermediate positions.

From Figure 2 it is apparent that the relation between overestimations and underestimations is reversed by the change from tactual to visual conditions. Under tactual conditions, chi-square shows a significant underestimation bias ($p<.001$), while under visual conditions, chi-square shows a significant overestimation bias ($p<.001$). It is obvious that the overestimation/underestimation ratio is different for the two sense modalities. Also, it is to be noted that these biases did not eliminate the bias

towards the midpoint (the central tendency) demonstrated by the decrease in overestimations and the increase in underestimations as the rod diameter increased, under both sensory conditions.

Figure 3 shows the mean perceived size of each of the nine intermediate rods for each subject, under each of the experimental conditions.

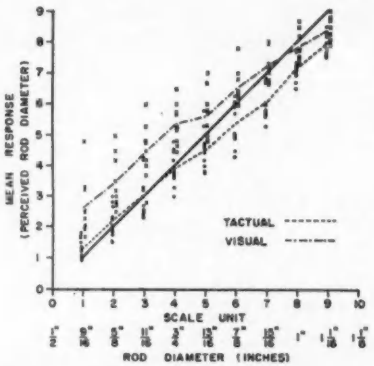

FIGURE 3. Mean constant error for tactual and visual interpolation, 10 subjects.

Subject means are shown by the two curves. The lower curve in Figure 3 shows the constant error across the nine interval positions for tactual interpolation. The constant error is negligible at positions "one" through "four," and negative at positions "five" through "nine." The upper curve shows a positive constant error for visual interpolation at positions "one" through "seven," and a negative constant error at positions "eight" and "nine." It is apparent that the two curves are essentially parallel, the visual curve being displaced by approximately one scale unit above the tactual curve. Means of individual subjects reveal a relatively small amount of overlap for the two kinds of interpolation.

It will be noted from Figure 2 and Figure 3 that there were no underestimations at the "one" position and no overestimations at the "nine" position, as would be expected in a situation which restricts responses to nine unit positions between the two reference marks, that is, between "zero" and "ten."

DISCUSSION

The results of this study reveal that the form and magnitude of interpolation errors are affected by the sense modality employed. When interpolating tactually, subjects tend to "feel" the diameter of a rod as

smaller than the actual diameter, while visual interpolation results in "seeing" the diameter of a rod as larger than the actual diameter, that is, the equal scale units employed in this study are not psychologically equivalent. Tactual and visual scales having units of psychological equivalence would differ considerably from each other and from the linear stimulus scale used here.

The results also show that in this kind of experiment subjects make fewer errors when interpolating tactually than when interpolating visually. (The greater accuracy of tactual interpolation is even more evident when error magnitude is taken into consideration.)

A satisfactory explanation of these phenomena has not been found to date.

Summary

An experiment was conducted to investigate scale interpolation under two different modes of sensory stimulation, tactual and visual. The scale "interval" consisted of a ½ in. diameter brass rod, designated as "zero," and a 1⅛ in. diameter rod, designated as "ten." Ten subjects were required to estimate the unit position within the interval represented by nine intermediate rods differing in diameter by 1/10-in. increments between the ½-in. and 1⅛-in. reference rods.

Subjects underestimated under tactual stimulation, that is, "felt" the rod diameter as smaller than the actual diameter. Subjects overestimated under visual stimulation, that is, "saw" the rod diameter as larger than the actual diameter. Tactual interpolation was more accurate than visual interpolation.

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A PILOT STUDY OF APHASIA AMONG BILINGUALS[1]

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THE STUDY OF APHASIA among people who speak more than one language has been undertaken in the main by specialists in aphasia, and several case reviews have been compiled. The course of aphasia among polyglots has been interpreted in terms of several different principles. First, cases have been reported which support the "rule of Ribot" (see 6, p. 76), which states that linguistic habits acquired early, as in childhood, are more resistant to aphasic damage than those acquired subsequently. The "mother tongue" is not only learned first but presumably is built up with more emotional meaning, thereby increasing its relative strength. An important paper by Pitres (5) offered a different generalization in order to account for his own observations of the effect of aphasia on polyglots. In essence, Pitres' is a habit strength principle which states that the language or languages most used before the aphasic insult will be the first to recover. The less well practised languages will be recovered less quickly and, if a language has been used very little before aphasia, that language might not be remembered or used at all afterward. Minkowski (4) presented several cases of bilingual aphasics which he proposed as exceptions to Pitres' principle and which also appear to be exceptions to the Ribot rule. Minkowski showed that an emotional or affective factor related to the use of one language might account for the survival of that language after the polyglot had suffered an aphasic insult. In short, cases have been presented which agree, and others which conflict with each principle. The conservative conclusion must be that aphasia can have various effects on the bilingual's languages, the particular post-aphasic pattern probably depending in some complex fashion on: the order in which the languages were learned, the comparative levels of skill attained in each, and the affective value each language has for the individual.

The study of the effects of an aphasic insult on the languages of a polyglot is also of interest and value to those who are primarily con-

[1]This research was supported by the Defence Research Board of Canada Grant D77–94–01–10. The members of the S.S.R.C. seminar on aphasia, held in Boston in 1958, assisted us with criticisms and suggestions for expanding an earlier version of this paper.

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cerned with bilingualism itself. Thus, for example, the recent work of Weinreich (6), which indicates the relevance of data from polyglot aphasics to various theories about the verbal behaviour of the "bilingual individual," makes it clear that our understanding of bilingualism would be greatly improved if data were systematically collected about the course of aphasia in bilingual patients.

Certain findings from our own and other research on bilingualism led us to a consideration of the data on aphasics. The point of departure was an hypothesis, developed by Weinreich (6) and Ervin and Osgood (1), which maintains that some bilinguals develop the same meaning for translated equivalents in their two languages, while others develop a different meaning for the concept in each language. The former would be characteristic of the "compound" bilingual and the latter of the "co-ordinate" bilingual for whom, theoretically, the two languages, or certain elements of the languages would function independently. This hypothesis is of value in understanding differences among bilinguals in their ease of switching from one language to the other, their control of interferences from the other language in any verbal situation, and their abilities to think and behave appropriately in the different linguistic contexts. This hypothesis was extended in a study by Lambert, Havelka, and Crosby (2) where it was concluded that the *learning contexts* in which the bilingual's two languages are acquired may well determine the functional independence of the languages. The more the learning contexts are "separated," either in time, cultural distinctiveness, or in distinctiveness of the setting of habitual usage, the more likely it is that bilingual "co-ordinateness" will develop.

There is the possibility that the functional relations of the bilingual's two languages have some systematic neural representation in those areas of the brain necessary to the functioning of language. The nature of this neural representation is necessarily largely a matter for speculation in view of how little is now known about language centres in the human brain. Our notion was that co-ordinate bilinguals should have more functionally separated neural structures underlying their languages than should compound bilinguals. Thus, the concepts "house" and "*maison*" which are more functionally independent for co-ordinate than for compound bilinguals would be "stored" in neural elements which have some sort of greater functional discreteness for the co-ordinate bilinguals.

It follows from this line of reasoning that any specific brain damage resulting in aphasia would be likely to affect all languages of the compound bilingual, but should lead to more selective disturbances for co-ordinate bilinguals. Thus, one would predict that if factors such as size and locus of brain damage could be held constant, co-ordinate

bilinguals would be more likely to show aphasic damage in one language system, while compound bilinguals would be more likely to show aphasic damage in all languages known. It should be recognized that factors of size and locus of damage can never be "held constant," and that even with a large sample of patients only general trends can be expected to emerge from a study of bilingual aphasics.

The present work sought to examine some data on aphasia in polyglots, to determine (*a*) if any relation exists between language learning contexts and the nature of the aphasic disorder, and (*b*) to what extent these data fit the general principles previously suggested, particularly the principles of primacy and "habit strength." Most reported cases on polyglot aphasics are anecdotal and incomplete: factual information on the language proficiencies of a patient before brain damage is rarely available. Such information as there is, in nearly every case, is based on the recollections of the patient or his family. Furthermore, the hospital environment in most communities is unilingual and the bilingual aphasic's first speech efforts may be forced into the language spoken in the hospital, with relearning taking place in that language only.

As source material we used the cases of European polyglot aphasics presented in a recent review by Leischner (3), and cases of polyglot aphasics obtained from several hospitals and rehabilitation centres in Montreal. In the collection of our own fourteen cases we were no more successful in obtaining complete information than other researchers. Interviews were held with the patient and with members of his family in an attempt to elicit data on his premorbid and present language skills. Information was obtained as to the language history of the patient, the times, conditions, and circumstances of acquisition, and use of the different languages, and the relative fluencies of the patient in each language. Each patient was interviewed to determine the present state of his language skills. Conversation was carried out in both (or all) languages known, and attention was paid to his expressive and receptive difficulties in each, his ability to switch languages spontaneously or on demand, to answer questions, to use words, and to read in each language.[2]

The extent to which the data fit such rules as a habit strength or primacy principle is summarized in Table I, where European and Montreal cases are kept separate. It can be seen that the Montreal cases and European cases fall into substantially different patterns. The European cases in most instances fail to support either a primacy or a habit strength principle, while in contrast most of the Montreal cases

[2]All case materials analysed for this study will be found in Appendices (I–III) which can be obtained from the first author. Translations of the cited works of Minkowski (4) and Pitres (5) are also available.

TABLE I

SUMMARY OF INSTANCES OF SUPPORT FOR VARIOUS PRINCIPLES

	Primacy (Ribot)		Habit strength (Pitres)		Affective (Minkowski)
	Pro	Con	Pro	Con	Pro
European cases	5	17	6	14	7
Montreal cases	8	2	9	?	1

are consistent with both principles (χ^2 values, corrected for continuity, for the difference between European cases and Montreal cases are 7.13, $p<.01$ (primacy) and 5.70, $p<.02$ (habit strength) respectively). In the European data there is evidence in seven cases for some affective factor which might account for the better survival of the language not first or better learned; in the Montreal data the one instance clearly involving some affective factor supports the importance of the first learned language. These apparent differences might be due to differences in the selection of cases: we investigated all bilingual aphasics available, cases reported in the literature may be the more dramatic ones taken as exceptions to expectation. We have no way of testing such a possibility.

The differences may also be interpreted, however, as evidence in favour of our original hypothesis. The typical pattern in the European patients is that the first learned language had been used for the greater (or greatest) period of time prior to aphasia, but a second language had also been acquired and used in the period prior to the aphasia. The language surviving aphasia best is characteristically a secondarily acquired language, a fact which conflicts with Ribot's generalization (primacy principle) and, to the extent that the second language is less known and used with less facility, with Pitres' (habit strength) principle as well. For the European patients the second language is typically learned in a context distinctly separated from the first, that is, the two languages are characteristically learned in a co-ordinate fashion. In Europe the polyglot may be forced to master the language of the new country of residence (its *only* language) and accordingly its acquisition (and retention after aphasia) will be of great personal importance. The seven cases in which an affective factor is evident suggest that a language which is emotionally important to the individual, although not used as often as another, may be the only language retained, or the one least damaged after aphasia. The typical Montreal case indicates that the first-learned language is also the one most used until the time of aphasia while the other language, learned early in life and used concurrently with the first, typically is not used as frequently as the first language. After aphasia, both languages are damaged but retain the order of

dominance which was developed prior to aphasia. The affective factor is less apparent, perhaps because in Montreal a greater freedom of use of all languages known is possible. It is likely that the Montreal scene encourages the development of bilingual compoundedness since essentially the same context for language learning is probably more likely to be used for all languages acquired. If we assume that the European and Montreal scenes encourage co-ordinate and compound bilingualism respectively, then the data offer some support for our hypothesis since the Montreal cases typically show a generalized disorder affecting both languages, while the European cases typically show a more specific-language disorder following aphasia.

A set of cases collected before the turn of the century by Pitres (5) was not mentioned or included in Leischner's 1948 review. Pitres' cases are of particular interest for our purposes because they were gathered in the southwest section of France, and because they include in all instances people who used French along with one or more languages, such as patois, Basque, Spanish, and Italian. In six cases, French was used most frequently and, with the exception of brief periods in two cases, was used continually throughout the patients' lives in France. It will be noted in Table II that these cases are strikingly similar to the

TABLE II

PITRES' CASES OF POLYGLOT APHASICS

Primacy (Ribot)		Habit strength (Pitres)	
Pro	Con	Pro	Con
5	1	6	0

Montreal cases in that both the Ribot and the Pitres principles are consistently supported, that is, the first learned language is the most used and also the one which returns first after aphasia. The generalization therefore seems appropriate that the language (or languages) which bilinguals use continuously from early life will probably be least vulnerable to aphasia. The Montreal cases are also consistent with this generalization in that two languages are more likely to be learned early in life and used concurrently in Quebec.

The Pitres cases also allow one further observation. The French people in the southwest section of France may learn a local patois and French in essentially the same context, much as Canadians may learn two languages in Montreal. That is, the patois and French may become "compounded" for these bilinguals. We would predict, then, that these

two languages should be similarly affected by aphasia. Three of Pitres' patients are polyglots with French and patois as two of their languages. Two of the patients suffered complete aphasic loss for a long period during which *both* languages did not return, and after three years, in each case, French was only poorly used while the patois was not used at all. It appears that language training after aphasia was carried out in French, and the difference between the ability to use the two languages after this long period may have been due to the training only. It is possible that these languages were learned as a compound system and that both were similarly affected (in this case equally damaged) by the aphasia, as our theory would predict. The third case is also consistent with expectations. This person learned French and patois from early years and later acquired several other languages in work situations. Six months following aphasia this patient was able to use *both* French and the patois fairly well, but still could neither understand nor use the other languages.

In conclusion, although the results are consistent with the theoretical analysis of compound and co-ordinate bilingualism, much more detailed information about the language history of each patient is needed before alternative interpretations of the results can be excluded. For example, we argued that Montreal and that region of France where a local patois is used are likely to be situations which encourage the development of compound bilingualism. These social environments also allow the continual and concurrent use of two or more languages, and the difference in freedom of *usage* of languages known may also account for the differences in the effects of aphasia noted when Leischner's "European" cases are compared with our own cases and with those of Pitres.

Summary

Several studies of the effects of aphasia among people who use more than one language were reviewed and three generalizations about the effects of aphasia in these cases were discussed. Classical cases of polyglot aphasics and new cases compiled in Montreal were analysed in order to test the hypothesis that the functional dependence or independence of polyglots' languages, determined by the manner in which the languages were originally learned, will determine, in part, how the languages are affected by an aphasic insult. Although the findings, derived from the analysis of cases, are consistent with the theoretical analysis, alternative interpretations cannot be excluded with the data available at present.

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TOWARDS A THEORY OF VIGILANCE[1]

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LITTLE IS KNOWN about the stability of perceptual performance as a function of time. One area which has excited considerable interest in recent years, however, concerns changes in perceptual performance in time under conditions where weak and randomly occurring signals, serially presented, must be observed and responded to. The best known, and among the earliest experiments in this field, have been reported by Mackworth (18, 19, 20, 21, 22).

Mackworth devised a Clock Test having a single rotating hand on a plain dial. Once each second the hand jumped forward 3.6 degrees to a new position, 100 jumps completing a revolution. Occasionally, however, the hand jumped double the usual distance and subjects responded to these double jumps, or "signals," by pressing a button. The interesting feature of these studies was that, as time progressed, fewer and fewer signals were detected. Typical data (22) showed that in four successive half-hour periods, the percentages of signals escaping detection were, respectively, 16, 26, 27, and 28. Such a decrement in performance with time has been demonstrated by more than twenty-five investigators working independently (see 1, 3, 16, 17, and 25 as representative). The decrement has been shown to occur in the absence of any change in the sensory threshold (15, 25, 26) and is thus considered to be central in origin.

THEORY

In a study of the effect of signal frequency Jenkins (16) found that, "the probability that an observer will detect a particular signal depends much more upon the prevailing or mean signal rate than upon the length of time that has elapsed since the preceding signal was detected." In examining these two possibilities Deese (12) advanced an expectancy hypothesis to account for the general level of performance during a vigilance task. It states that "the probability of detection—is determined by a large and rather indeterminant number of signals preceding the signal in question—the observer—continuously performing a kind of

[1]Defence Research Medical Laboratories Project no. 234, DRML Report no. 234–3, PCC no. D77–94–20–42, H.R. no. 165.

averaging of previous input in order to extrapolate the results to future behaviour of the search field," and so, "expectancy should be low immediately after a signal, should increase as the mean intersignal interval is approached, and finally should become quite high as the intersignal interval grows beyond the mean."

This hypothesis implies that the observer would be "eternally hanging on an expectant limb" after a series of signals terminated, and consequently has been expanded (6) to read, "as the interval grows still longer expectancy again falls to a low level." It should be noted that the term "expectancy," as used in this paper, does not necessarily imply any conscious formulations on the part of the observer. The degree to which he is aware of such expectancies is unknown.

The work of Mowrer (23) serves admirably to illustrate the expanded hypothesis. In order to "obtain an *objective* record of the course of expectancy," he used a simple reaction time technique, subjects responding to a tone which appeared "at an unvarying interval of 12 seconds." Occasional "test trials" were inserted, these consisting of intervals of as small as 3 to as large as 24 seconds. "As the test interval approached the standard interval the reaction time became progressively shorter (with rising expectancy) until, at the 12-second test interval–

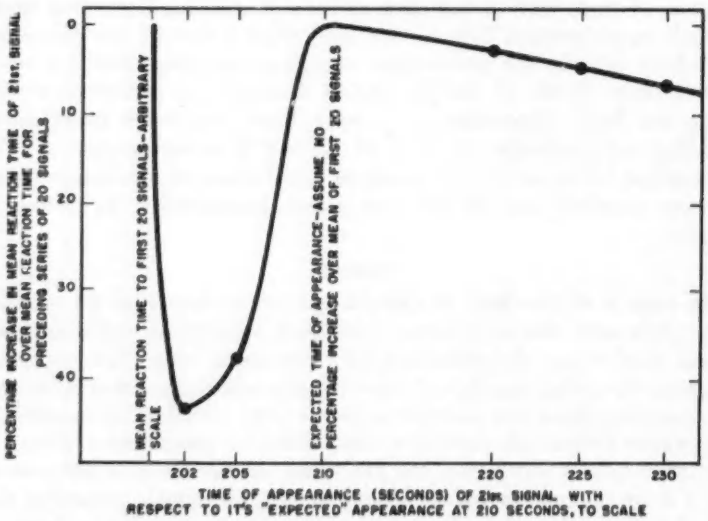
PERCENTAGE INCREASE IN MEAN REACTION TIME OF 21st SIGNAL OVER MEAN REACTION TIME FOR PRECEDING SERIES OF 20 SIGNALS
0
10
20
30
40
MEAN REACTION TIME TO FIRST 20 SIGNALS—ARBITRARY SCALE
EXPECTED TIME OF APPEARANCE—ASSUME NO PERCENTAGE INCREASE OVER MEAN OF FIRST 20 SIGNALS
202
205
210
220
225
230
TIME OF APPEARANCE (SECONDS) OF 21st SIGNAL WITH RESPECT TO IT'S "EXPECTED" APPEARANCE AT 210 SECONDS, TO SCALE

FIGURE 1. Showing the mean percentage increase in reaction time to a 21st signal appearing at shorter and longer intervals than that employed in the preceding regular series $N = 12$.

which was, of course, the same as the standard interval—the obtained reaction time was "normal". . . . As the test intervals varied beyond 12 seconds, up to 24 seconds, the average reaction time again increased but not to the same heights it had reached on the shorter test trials" . . . (23). Mowrer's study has been repeated (4) using series of 20 unvarying intervals of 10 seconds, followed by a twenty-first "unexpected" interval of 2, 5, 20, 25, and 30 seconds, on separate trials.

In Figure 1 the data from this study are plotted in terms of the percentage increase in time to respond to a twenty-first signal inserted after the five "unexpected" intervals. For signals at 202 and 205 seconds the mean response time was longer (43 and 37 per cent respectively), than the mean of the preceding series. This difference is significant at the 1 per cent level although the apparent downward trend of the three "late" signals is not.

Figure 1 is interpreted as the shape of the expectancy function—expectancy drops to a low level shortly after each signal, mounts rapidly as the next signal is expected, and then tends to taper off if the expectancy is not confirmed. Experiments employing regular intervals of two minutes, followed by "unexpected" intervals, have yielded similar results.

Supporting Data

In addition to explaining the decrement in performance often found in vigilance tasks, a satisfactory model must also explain the effects of at least six factors which are known to retard or accelerate the decrement. These factors are given below, each followed by a brief description of how the position outlined above can account for their known effects.

(1) *Rate of signal appearance.* A greater percentage of signals is detected, or signals are responded to more quickly, as signal frequency increases (8, 10, 11, 16, 24).

This follows for two reasons: (i) observers have a larger sample of data upon which to base expectancies, and (ii) it has been shown (28) that observers can estimate short intervals with greater precision than longer intervals. It should be noted that we are not concerned here with the oft-found decrement in performance, but with the over-all level, that is, with the proportion of signals detected during a complete session.

(2) *Inter-signal interval.* The more regular the temporal interval between signals, the more signal detections (4, 3).

Here we are concerned with the decrement in detection performance in time. The accuracy of perception of the temporal structure of a series of signals must be a function of the degree of regularity of the series, and the more accurate the perception the more probable the confirmation

of expectancy. For signals occurring with less apparent regularity, confirmation of expectancy is less probable. Lack of confirmation lowers the apparent signal frequency, with the consequent lowering of the over-all level of performance. This lowering of the over-all level of performance proceeds in successive steps in time. These steps are invariably masked when the results from individual subjects are pooled, and appear as a smooth decrement.

At some point in time the observer abandons his efforts to build expectancies. This occurs when the apparent frequency is so low that the intervals are too long to permit extrapolation with any precision. The probability of signal detection is now determined solely by chance events, that is, he is looking at the right place at the right time. Such chance events, being independent, result in a consistent probability of detection as time progresses, that is, in performance which shows no further decrement, as typified, for example, in Mackworth's studies (22).

The above explanations of the effects of signal frequency and interval regularity are basic to the expectancy position. Expectancy is a function of signal frequency and interval regularity. It follows that any condition which reduces either frequency or regularity, or both, will result in a lower over-all level of performance or a greater decrement in time, or both.

(3) *Signal magnitude.* Signals of large magnitude (size, duration, intensity) escape detection less frequently than those of smaller magnitude (1, 16, 22).

Such signals make confirmation of expectancy more probable, simply because the greater the magnitude the greater the probability of perception.

(4) *Knowledge of results.* Knowledge of results during a vigilance session prevents a decrement in performance from occurring (22).

Explanation of this effect is based upon the proposition that knowledge of results serves to establish perception of the true sequential nature of the series and so to increase the probability of expectancy confirmation, that is, knowledge of results, in this particular context, is synonymous with feedback. In other words, telling an observer, "yes, that was right," or, "you missed one there," tells him, in effect, that there is a signal *now*, and nothing more. We would not, therefore, expect knowledge of results to be a potent factor until the task had proceeded for some time, and indeed Mackworth found "a clear advantage in favour of the men who were supplied with knowledge of results, except during the first half-hour" (22).

The proposition that knowledge of results in a vigilance situation serves simply as feedback by revealing the true temporal nature of the series

has recently been tested (4). Three experimental conditions were compared. In one, the "no information" condition, no information was given when a signal was detected or missed. In the second, knowledge of results was given: a small display was illuminated for one second above the main display, to read "correct," "missed," or "false," as appropriate. In the third or "feedback" condition a missed signal was repeated a second, a third, or an even greater number of times, at intervals of five seconds until it was responded to, but the observer was *credited with a miss even though he eventually responded.* The Mackworth intervals mentioned above were employed in this study as they are known to produce a decrement when no information is supplied. Seventy-five paid female subjects were employed, twenty-five being randomly assigned to each condition. (The procedure of testing each subject under each condition was avoided because of the possibility of order effects.)

The data are shown in Figure 2. The decrement in the "no information" condition is significant at the 0.02 level of confidence. As hypothesized, there is no signficant decrement in the "knowledge" or "feedback" conditions. The general superiority of the "feedback" group is attributed to chance differences between the groups.

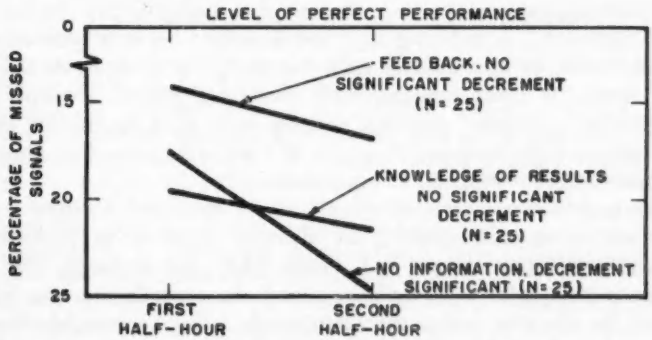

FIGURE 2. Showing the percentage of signals missed under each of three experimental conditions during the first and second half-hour periods.

(5) *Environmental factors.* Significantly more signals are detected at 79°F. than at 70° or 90° when subjects are dressed in shorts (20, 22). High ambient noise levels also impair performance (9).

The explanation of these effects is simply that any distraction which competes for attention with the vigilance task will lower the apparent signal frequency and consequently result in a deteriorated performance.

(6) *Knowledge of signal location.* When signals appear at locations which cannot be predicted, performance is generally poorer than when the location is known, that is, when visual search is not involved (15). This follows because under the condition of uncertainty of signal location an expectancy may be "correct," but the signal may appear at a location not being scanned at that moment. Such unconfirmed expectancies will serve to lower the apparent signal frequency. Supporting data have been reported (7, 15, 26).

Discussion

An attempt has been made here to examine an expectancy hypothesis of vigilance proposed by Deese (16), expand it, illustrate it, and present some supporting data.

Two merits of the position outlined here are worth emphasizing. First, in vigilance experiments performance never becomes nil, that is, the curve of performance always becomes asymptotic with the time base and never intersects it. The expectancy position can account for this phenomenon. Second, it has been shown that knowledge of results can assume new meaning. Knowledge of results is typically (and vaguely) considered as a motivating factor—something akin to the use of incentives (the individual approach), or to the use of authority or peer figures (the social approach), in inducing high and sustained levels of performance. But the mode of operation of such knowledge in a vigilance task has been shown to differ fundamentally from this general concept: here "knowledge of results" provides nothing more than *knowledge* of the true nature of the temporal structure of a series in order that observers can make accurate temporal extrapolations.

This approach has avoided what is an obvious and possibly a most important factor in determining the efficiency of perceptual performance in time—motivation. Fraser has shown (14), for instance, that performance is superior on a vigilance task if the experimenter sits quietly behind the observer, rather than outside the room, presumably because the experimenter is an authority figure in this particular situation. Worth mentioning, too, is our understanding that at sea officers of the watch make many more sightings than do members of the watch. (In passing we can note the findings (2, 20, 25) that there is no relation between intellectual ability and performance on a vigilance task.) Data, however, are few.

The theoretical position outlined above, however, should be true at any level of motivation on the part of the observer and even in the case of a changing level of motivation. The performance of even the most highly motivated observer must in time decline if the situation is such

as to produce a decrement—small, brief, infrequent signals, irregularly spaced, with no feedback concerning performance. On the other hand, the least motivated subject could turn in an acceptable performance if signals were large, prolonged, frequent, fairly regularly spaced in time, with feedback proved.

In closing it is worth pointing out that in the experiments described here the measure of performance has been the percentage of signals escaping detection. Many other measures have been reported. Considerable emphasis has been placed upon the "effective threshold" technique, which consists basically of increasing signal magnitude in steps until it *is* reported, that is, apparent signal frequency and input frequency are the same (13). In view of the data reported above concerning the effects of feedback it appears that use of the "effective threshold" technique will generate data which are not descriptive of the actual situation.

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THYROID FUNCTION AND ACTIVITY, SPEED, AND TIMING ASPECTS OF BEHAVIOUR[1]

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IN A PREVIOUS STUDY (6) evidence was presented that variations in thyroid function affect the activity, speed, and timing aspects of behaviour measured by certain objectively scorable tasks. The tasks used as indices of these and other aspects of behaviour were *speed of tapping, auditory reaction time, visual reaction time, time estimation,* and *leg-lift persistence.* In that study it was shown that hyperthyroid patients differ from normal control and patient control subjects in performance on these tasks, and that therapy usually produces changes in their performance in the direction of the data for the subjects without known endocrinological disorders.

The present study presents evidence that a different type of variation in thyroid function is also paralleled by systematic changes in the same aspects of behaviour. Specifically, it deals with the changes in behaviour brought about by thyroid therapy in hypothyroid patients. This study compares the performance on the same tasks as were used in the earlier study (*a*) of hypothyroid patients before and after thyroid therapy, (*b*) of hypothyroid patients and control subjects, and (*c*) of the hypothyroid patients of this investigation and the hyperthyroid patients tested in the earlier investigation.

METHOD

Subjects

The experimental or hypothyroid group consisted of 32 out-patients of the endocrine clinics in 2 general hospitals, who had been diagnosed as hypothyroid by a group of endocrinologists in clinical conferences. Of the patients, 20 were female, ranging in age from 22 to 67, and 12 were male, ranging in age from 29 to 58. Control data were collected from 2 other groups: (*a*) 32 patient control Ss from

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the general-medical and surgical clinics, under treatment for a variety of ailments, but with no known hormone imbalance; this group was matched in age range and male-female ratio with the hypothyroid patients; and (*b*) 116 normal control Ss, 76 from a Canadian Air Force training school, 20 from the introductory psychology course at McGill University, and 20 hospital technicians. With the exception of the data obtained from the group of hospital technicians, the control data reported here were obtained in the previous study. The hyperthyroid patients, whose performance was compared with the hypothyroid patients of the present study, were also those whose performance was reported in the earlier investigation.

Tasks and Measures

The tasks and measures employed in this investigation have been described before (6). In general, they were as follows:

(1) *Speed of tapping.* Subjects, starting and stopping on verbal signals, tapped with a pencil over the centre of an index card, mounted on a speed-of-tapping apparatus. Score was the number of taps in a 10-sec. period.

(2) *Reaction time.* Simple reaction-time apparatus presented lights as visual stimuli and a buzzer as an auditory stimulus. Score was the time between the onset of the stimulus and completion of key-pressing by S.

(3) *Time estimation.* A method of reproduction was used in which S was required repeatedly to reproduce an interval that was presented to him only once. The 15-sec. duration to be reproduced was signalled by a light stimulus. Score was the mean time for 12 reproductions.

(4) *Leg-lift persistence.* Seated S held his leg 6 in. above the seat of a second chair for as long as he could. Score was the mean time in seconds for 2 trials for normal control Ss, and for 1 trial for all other Ss.

Procedure

Hypothyroid patients performed the tasks in the clinic before the onset of desiccated thyroid therapy and again when they had recovered. The time between the 2 testing periods varied between 6 weeks and 5 months. Data on patient control Ss were also obtained in the clinic. Twelve of the university students and the 20 hospital technicians were tested twice, with a 6-month interval between the 2 testing sessions. All tasks were administered by the experimenter, in the order in which they are listed above.

Results

Table I shows the mean scores before medical therapy of the hyperthyroid patients who were previously studied, of normal control subjects and patient control subjects, who served as comparison groups for the whole investigation, and of the hypothyroid patients who were the subjects of the present study—the last both before and after thyroid therapy.

The data for the hypothyroid patients indicate that, concomitant with thyroid therapy, significant differences appeared on all the experimental tasks, with the exception of leg-lift persistence. Before therapy, the hypothyroid patients were faster in speed of tapping, had longer reaction

TABLE I

MEAN PERFORMANCE OF HYPERTHYROID PATIENTS BEFORE THERAPY, OF HYPOTHYROID PATIENTS BEFORE AND AFTER THERAPY, AND OF NORMAL CONTROL AND PATIENT CONTROL SUBJECTS

Experimental tasks	Hyperthyroids before therapy ($N = 36$)	Normal controls ($N = 116$)	Patient controls ($N = 32$)	t	Hypothyroids before therapy ($N = 32$)	t	Hypothyroids after therapy
Speed of tapping (taps in 10 sec.)	32.50	59.60	50.40	2.00*	40.00	2.05*	30.80
Auditory reaction time (sec.)	.56	.34	.40	7.24***	.88	8.63***	.38
Visual reaction time (sec.)	.77	.41	.46	8.54***	.96	8.66***	.45
Time estimation (sec.)	8.70	18.64	21.60	1.38	22.60	2.00*	17.40
Leg-lift persistence (sec.)	14.40	48.70	13.10	1.87	9.80	1.20	12.70

*$p = .05$. ***$p = .001$.

times, and showed greater underestimation of elapsed time[2] than after therapy. The changes in performance after therapy were all in the direction of the means for the normal control group, with the exception of the speed-of-tapping performance, which became significantly slower, and the leg-lift persistence time, which did not change significantly. Thirty-two of the normal control subjects who were retested six months after original testing showed no significant change in their performance on any of the tasks.

A comparison of the performances of hypothyroid patients before therapy with that of patient control subjects showed significant differences between the two groups on three of the measures, namely, speed of tapping and auditory and visual reaction times, the differences being in the same direction as those between hypothyroid patients and normal control subjects. There was no significant difference between hypothyroid patients and patient control subjects on either time-estimation or leg-lift persistence scores. (It should be noted here that the

[2]According to Bindra and Waksberg (1) in studies of time estimation, where the method of reproduction is used, the terms *overestimation* and *underestimation* of elapsed time are not strictly applicable. These terms, however, are included here to make the present study comparable with other studies that have used this terminology (4, 6). Accordingly, *underestimation of elapsed time* here refers to "Subjective temporal units larger than objective temporal units *during reproduction*," whereas *overestimation of elapsed time* refers to "Subjective temporal units smaller than objective temporal units *during reproduction*."

performances of hypothyroid patients before therapy and normal control subjects were significantly different for all five tasks.)

Further examination of Table I reveals that both hyperthyroid and hypothyroid patients, before therapy, differ from normal control subjects on all of the tasks, and from patient control subjects on most of the tasks. The direction of the differences should be noted. On the perceptual motor tasks (speed of tapping, auditory reaction time, and visual reaction time) performances of both hyperthyroid and hypothyroid patients deviate from those of normal control and patient control subjects in the same direction, that is, they are both slower. On the primarily perceptual task of time estimation, while the performance of the hypothyroid patients does not differ significantly from that of the patient control subjects, the performances of both hyperthyroid and hypothyroid patients deviate significantly from normal control subjects, and in the opposite direction.

Discussion

Since the performance of hypothyroid patients on leg-lift persistence (like that of the hyperthyroid patients of the previous study) neither changes significantly after therapy, nor differs significantly from that of the patient-control subjects, it must be assumed that performance on this task is not affected specifically by changes in thyroid function, but may be affected by a general state of health. For this reason, the leg-lift persistence task will not be further discussed.

With regard to the tasks involving speed of tapping, auditory reaction time, and visual reaction time, clinical descriptions of hyperthyroid and hypothyroid patients seem to suggest that, before therapy, speed of tapping and speed of reaction for hyperthyroid patients should be faster than those for normal subjects; and for hypothyroid patients should be slower than normal. In fact, as judged by the results of this investigation, this is not so. The hypothyroid patients are indeed slower than normal subjects on these tasks, but so are the hyperthyroid patients.

One way of accounting for the inconsistency between the clinical picture and the present results is in terms of the concept of *arousal*. By arousal is meant some kind of intensitive dimension of behaviour, the one extreme being typified by deep sleep, or general anaesthesia, and the other extreme by acute excitement. Now, whatever the other differences between hyperthyroid and hypothyroid patients may be, they also appear to differ in level of arousal. Thus, if one were to place patients along the arousal continuum, hypothyroid patients would be found toward the lower end of this continuum and hyperthyroid patients toward the higher end. Normal subjects would occupy an intermediate level. The present

interpretation begins with the assumption that the observed differences in performance between the thyroid subjects and the control subjects, as well as the differences before and after therapy, are attributable to differences in level of arousal. If this assumption is correct, the problem of the exact relations between level of arousal and task performance becomes relevant, and the differences and changes in performance observed in this investigation become a part of that general problem.

Freeman (2), Schlosberg (5), and Hebb (3), among others, have suggested that the relation between arousal and efficiency of performance is curvilinear, having the shape of an inverted U. That is, proceeding from a low level, such as somnolence, increase in arousal would have a beneficial effect on performance up to a certain level, beyond which any further increase in arousal would have deleterious effects on performance. This means that, other things being equal, there is an optimal level of arousal for performance on any given task. If, as suggested, hypothyroidism represents a subnormal state of arousal and hyperthyroidism a supernormal state of arousal, then one would expect both the thyroid groups to perform less well than the normals, assuming that the normals are near the range of arousal which is optimal for efficient performance on these tasks.

After therapy, the speed of tapping performance of hypothyroid patients did not become like the performance of the normal control group. Instead, their scores changed in the direction of the performance of the hyperthyroid patients before therapy. That is, the hypothyroid patients' performance on the speed-of-tapping task became less efficient. One might postulate that the thyroid extract given as therapy to the hypothyroid patients increased level of arousal beyond the range for normals sufficiently to exercise deleterious effects on the speed-of-tapping task. The treatment did not, however, have a deleterious effect on the reaction-time performance. Since speed-of-tapping and reaction-time scores are not significantly correlated (Pearson $r = .222$), it may be assumed that they involve different types of responses, and thus a different optimal level of arousal for efficient performance.

If the results on the time-estimation task are now considered, it will be recalled that, unlike the scores on the speed-of-tapping and reaction-time tasks, the time-estimation scores for hyperthyroid and hypothyroid patients before treatment did deviate in opposite directions from those of the normal control subjects. Compared with all the control subjects, the hyperthyroid patients consistently overestimated elapsed time, whereas compared with the normal control subjects the hypothyroid patients consistently underestimated it. That this differential performance in time estimation is also related to level of arousal is supported by Milner's (4)

finding that benzedrine injections and electrical stimulation of the brain-stem in the rat, both of which are presumed to increase arousal, result in overestimation of elapsed time; injections of sodium amytal and phenobarbital, which decrease arousal result in underestimation of elapsed time. However, why arousal affects performance on the time-estimation task in one way and performance on the speed-of-tapping and reaction-time tasks in another is not clear.

It seems reasonable to conclude that one of the consequences of variations in thyroid function is variation in level of arousal. Level of arousal, in turn, affects the activity, speed, and timing aspects of human temperament. The effects of level of arousal on these aspects of temperament appear to be dependent in part on the type of tasks employed. The mechanisms by virtue of which level of arousal is related to the performance on the tasks employed, and the underlying processes involved in the tasks, remain to be investigated.

Summary

Thirty-two hypothyroid patients were compared before and after thyroid therapy with thirty-two patient controls, sixteen normal controls, and thirty-six hyperthyroid patients (tested in an earlier study) on the following tasks: speed of tapping, auditory reaction time, visual reaction time, time estimation, and leg-lift persistence. Measures on all the tasks, except leg-lift persistence, showed significant changes after thyroid therapy, in the direction of those obtained from normal control Ss. Hypothyroids before therapy also differed significantly from the patient controls in speed of tapping and the two reaction-time tasks.

In order to account for the fact that the performance of hypothyroid patients and that of hyperthyroid patients did not always deviate from the normal Ss in opposite directions, it was argued that variations in thyroid function influence the general level of arousal. The observed changes in performance were then interpreted as special cases of the general relation that exists between arousal and performance.

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EMG CHANGES IN A RETROACTION EXPERIMENT USING A PERCEPTUAL MOTOR TASK[1,2]

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ONE OF THE MAJOR difficulties in making statements concerning perceptual motor learning has been that of discovering measures which are useful in many differing situations. The kinds of statements made on the basis of empirical studies have depended to a considerable degree on the particular aspect of behaviour observed. "Learning" might be inferred from such varied measures as latency, amplitude, frequency, and duration of a response, and these might be quite differently related to experimental variables.

Level of muscular tension is a measure which is not task-centred, as are the above variables, and would appear to be especially useful in interference studies involving incompatible response tendencies. Very little previous experimental work bears directly on this point. In a number of studies muscular tension has been measured during the performance of motor tasks, but the data appear to be conflicting. Malmo, *et al.* (11), Malmo and Davis (12), Smith (17), and Bartoshuk (1, 2) found increasing "gradients" of tension during short mirror-tracing tasks, and Surwillo (19) using a tracking task found a similar gradient. On the other hand, in earlier studies, it was found that tension decreased during performance (3, 9) and two experiments showed an increase followed by a decrease (4, 20). In the latter studies, the interaction of the elimination of errors and increasing speed of movement was suggested to account for the results. (Speed of movement has typically not been controlled in experiments of this kind although Bartoshuk's analysis indicated that tracing speed could not account for his observed gradient.) Only one study has been directly concerned with the interaction of competing response systems. Davis (5) found, in a discrimination reaction test, a progressive decline in pre-stimulus tension in the active

[1]This report is based on a dissertation submitted to the University of Toronto in partial fulfilment of the requirements for the Ph.D. degree in Psychology. The study was conducted as part of a research project (9401-02) made possible by a grant from the Defence Research Board of Canada to Professor A. H. Shephard of the University of Toronto.

[2]The author is greatly indebted to Professor Shephard and to the late Professor D. Y. Solandt of the Faculty of Medicine, University of Toronto, for their advice, criticism, and material aid.

arm, and an increase in tension accompanying task reversal. The decline during learning was interpreted as due to the weakening of irrelevant response tendencies, and the increase after task reversal as due to the interaction of incompatible response tendencies.

The purpose of the following experiment was to determine whether muscle tension varies systematically with practice on a two-hand tracking task, and with the successive acquisition of competing response tendencies. The effect of competition of response tendencies upon performance has typically been investigated by means of a retroaction experiment, in which one task (IL) is interpolated between the learning (OL) and relearning (RL) of another. Using the Two-Hand Coordinator, sizable decrement in performance from the end of OL to the beginning of RL is produced when the interpolated task is the reversed form of the criterion task (**10, 13**). This decrement is most adequately accounted for in terms of a two-factor theory of forgetting. That is (*a*) the response tendencies established in IL compete with those acquired in OL at the beginning of RL, and (*b*) the response tendencies acquired during OL are weakened during IL. Shephard (**15**) has suggested that these two processes might best be subsumed under the concepts of acquisition and extinction, and provided convincing evidence for the extinction factor operating in perceptual motor learning.

From a two-factor theory, the expected course of change in muscular tension during performance on the Two-Hand Coordinator might be as follows. Initially, tension level will be high, reflecting interaction between low-strength appropriate tension and all others. As learning progresses the frequency of appropriate tensions will increase, and that of inappropriate tensions will decrease. The majority of inappropriate tensions will probably be incompatible with the appropriate ones, and therefore their decrease will lessen the opposition to be overcome by the appropriate tensions. The increase in appropriate tensions would be limited by the nature of the task. Thus, the net effect would be to reduce average tension. This process would be expected between appropriate and inappropriate responses whether in OL, IL, or RL.

At the beginning of IL, the necessity for making new responses renders previously appropriate tension patterns inappropriate, tending to produce an increment in average tension over that at the end of OL. During IL tension should again decline, and at the beginning of RL an increment should be again observed. The level of tension in RL would be expected to be an increasing function of the strength of the interfering tendencies, and therefore of amount of IL.

In this prediction, an unlearning or extinction factor has been assumed as operating to reduce inappropriate tensions during practice on one task. That is, inappropriate tensions are progressively decreased. In

addition, a comparison of changes in tension on the reversed task with and without prior learning of the standard task, might provide supporting evidence for such a factor. It might be expected that muscular tension in the former would decrease more slowly than in the latter.

In experiments on the effects of induced tension on performance, residual muscle tensions have been noted several minutes after the termination of overt behaviour (6, 15). This might be an additional mechanism related to the decrement produced in retroaction experiments. Tensions remaining after OL may interfere with the appropriate responses in IL, and those remaining after IL with the original appropriate responses. If the hypothesis were correct, then the amount of competition between tensions in RL should be less if interpolated practice is immediately after OL than if it is immediately before RL, and average tension should be less in the former case. In the following experiment, provision was made for examining this prediction.

Method

Apparatus

The apparatus consisted of: (*a*) a motor task with associated apparatus for timing practice and rest intervals and for measuring performance, and (*b*) amplifying and recording equipment for measuring electrical output of muscle.

The motor task was a Two-Hand Coordinator (14), modified in that the two control cranks were parallel to the frontal plane of a subject. In addition, provision was made for reversing the control-display movement relations. Thus, in the "standard" task, clockwise rotation of the right-hand crank moved the follower to the right and counter-clockwise moved it to the left; clockwise rotation of the left crank moved the follower away from the subject, and counter-clockwise moved it toward him. In the "reversed" task, these movement relations were reversed while maintaining the right-lateral and left-longitudinal relations.

The measure of performance was time-on-target, measured to 0.01 sec. by Standard Electric Timers. Practice and rest intervals were pre-set and controlled by means of an automatic switch (8). A transfer switch (7) was used to permit the recording of time-on-target in segments of continuous practice.

Electrical potential output of muscle (EMG) was used as a measure of muscular tension. Muscle potential was measured from the left forearm flexor, throughout all practice periods, using cellulose sponge electrodes. These electrodes were approximately 2 in. apart and were held in place by inserting them under the edges of a Lastanet sleeve. The ground electrode was a silvered metal plate attached at the wrist. Lead wires were taped to the arm to prevent them from pulling the electrodes out of place, or from interfering with task performance.

Electrode potential was amplified by an Edin 8131 High Gain Amplifier to a level sufficient to drive an Edin 8002 ink-writing galvanometer. The amplified potential was fed directly to one pen of the two-pen recorder, in order to permit the detection of any artifacts. Into the second pen of the recorder was fed an integrated potential, and this channel provided the measurable record of potential changes. This record was obtained by rectifying the amplifier output and leading it through a resistance-capacitance network and a Hunter DC amplifier. The condensers of

the integrator were discharged at 10-sec. intervals by means of cams attached to the automatic switch. Integration was essentially linear far beyond this 10-sec. interval, since the time-constant of the resistance-capacitance circuit was 60 sec. Thus, average muscle potential in each 10-sec. interval was obtained from the pen-recorder tape by measuring the maximum height reached before discharge.

Calibration of the amplification-integration system was done by injecting signals of known voltage into the Edin amplifier input and measuring the 10-sec. pen deflection resulting from the integrated output. A Hewlett-Packard Model 206A Audio Signal Generator was used to generate the known voltages.

Subjects

As Ss 50 male undergraduates in the Introductory Psychology class at the University of Toronto were used. The age range was 18 to 28 years.

Procedure

The 50 Ss were divided into 5 groups, 4 of which practised the standard task for 15 spaced 1-min. trials (OL) and after an interval of 18¾ min., relearned this task for 5 trials (RL). During the interval between OL and RL, Group 1 practised the reversed task for 10 trials, Groups 2 and 3 for 5 trials each, and Group 4 rested. The 5 trials of Group 2 were at the beginning of the IL period, while those of Group 3 were at the end. The remaining 10 Ss (Group 5) practised the reversed task without prior learning of the standard task.

Practice-rest conditions throughout the experiment were 60-sec. practice, 30-sec. rest. Spaced practice conditions were used to facilitate the acquisition of response tendencies. Time-on-target and EMG were recorded during all practice periods.

Results

Time-on-target

Means of time-on-target for OL, IL and RL for all groups are plotted in Figure 1. Ten trials produced a decrement in performance between OL and RL (Group 1), whereas the rest group and the groups having five trials IL showed increments. The differences between groups in changes from OL to RL were tested by means of an analysis of covariance on the initial level of RL with final level of OL as the covariant. The test for parallelism of the individual group regressions indicated no interaction between OL-final and change between OL and RL ($F = 1.26$, 3 and 32 df, $p < 0.25$). The covariance analysis indicated between-groups differences ($F = 3.93$, 3 and 35 df, $p < 0.025$), but from inspection of the data it was clear that this high F was produced by the deviation of the group given ten trials IL from the other three, and that no significant differences among Groups 2, 3, and 4 could be expected.

One further comparison of performance changes was made. From Figure 1, it can be seen that the two groups which were given ten trials on the reversed task appear to differ in rate of increase of performance on that task. Group 5, which had received no prior practice on the standard task, began at a lower level and finished at a higher level than Group 1, which had just completed fifteen trials on the standard task.

However, the null hypothesis could not be rejected (F (groups by trials) $= 1.36$, 9 and 162 df, $p < 0.10$).

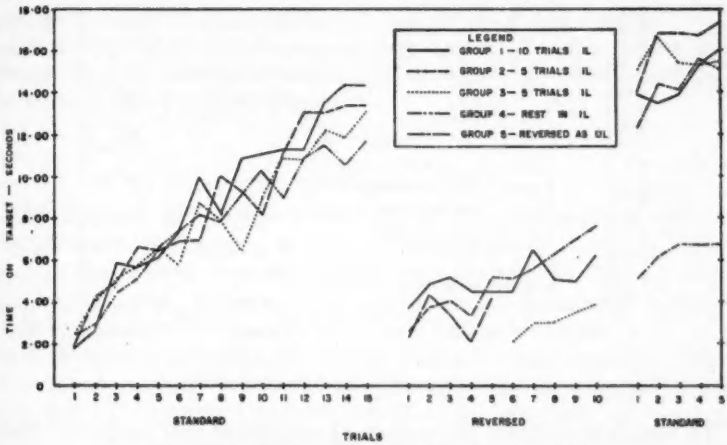

FIGURE 1. Mean time-on-target for OL, IL and RL.

EMG

Means of EMG for OL, IL and RL for all groups are shown in Figure 2. During OL, EMG decreased as hypothesized, but only after an initial increase extending over the first few trials. No interaction was found between groups and trials ($F = 0.298$). There are the expected differences between trials ($F = 5.41$, 14 and 504 df).

At the beginning of IL, muscle potential did not return to a higher level as predicted. There was a slight increment in average potential from the end of OL to the beginning of IL for each of the three groups which practised the interpolated task, but the variability in these data was such that the null hypothesis could not be rejected.

Little can be said, also, about changes during the course of II Groups 2 and 3 tended to decrease progressively from the beginning of practice, whereas Group 1 followed a pattern similar to that of OL: that is, an initial increment followed by a progressive decline.

Between the end of OL and the beginning of RL, Groups 1 to 4 each showed a decrement in EMG. For Groups 1, 2 and 3, which had practised the intervening reversed task, this was the opposite of the predicted direction of change. However, the amounts of decrement conform to the original major hypothesis. That is, the smallest increase is associated with the largest amount of practice on the reversed task, and the greatest is that of the rest group (Table I).

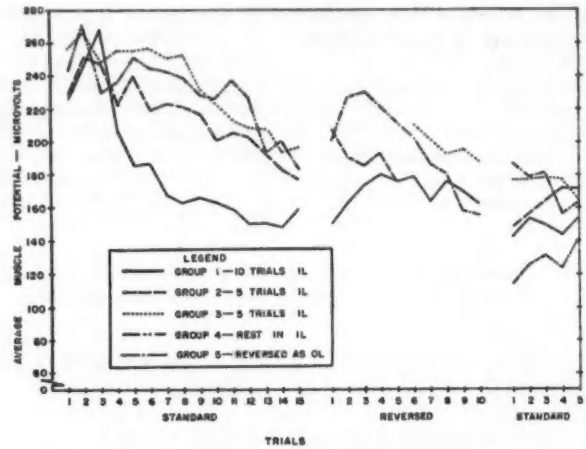

FIGURE 2. Mean EMG for OL, IL, and RL.

To test these changes, an analysis of covariance was used, with final level of OL as covariant. The test for parallelism of the individual group regressions of initial RL score on final OL score indicated no interaction between number of trials in IL and level at the end of OL ($F = 0.88$). The covariance analysis indicated a difference between groups ($F = 5.70$, 3 and 35 df, $p < 0.001$). However, as suggested by Figure 2, the high F ratio might be due to the deviation of the rest group from the other three. This explanation was substantiated by an individual test of the difference between Groups 1 and 2 ($F = 1.03$, 1 and 17 df, $p < 0.25$). As noted earlier, in terms of performance the effect of ten trials IL was apparent, whereas that of only five trials was not. The EMG analysis, on the other hand, indicates an effect due to both amounts of reversed task practice.

An analysis of the differences between Group 5 (no original practice on the standard task) and Group 1 (ten trials reversed after fifteen trials standard) in EMG changes during reversed practice, indicated a difference in rate of decrease ($F = 2.56$, 9 and 62 df, $p < 0.01$). Note that the earlier performance analysis showed no difference in rate of increase.

TABLE I

DECREMENT IN EMG BETWEEN THE END OF OL AND THE BEGINNING OF RL

	Group 1 (10 trials IL)	Group 2 (5 trials IL)	Group 3 (5 trials IL)	Group 4 (rest)
Decrement (microvolts)	17	28	21	70

It can be observed from Figure 2 that the pattern of change in EMG for Group 5 on the reversed task is similar to that of Groups 1 to 4 on the standard task. That is, there is an initial increase followed by a progressive decrease. From an inspection of the data, it was clear that there were no significant differences between Group 5 and standard task groups. That is, differences between the standard and the reversed task do not influence the EMG pattern.

Discussion

The decrease in average tension during OL is consistent with an interpretation of learning in terms of an increase in the tendency to make appropriate responses and a decrease in the tendency to make inappropriate ones. In terms of muscle tension, a decrease in inappropriate tensions would result in a decrease in the resistance to be overcome by appropriate ones, and would tend to reduce average tension. In a paced tracking task, such as that used in this experiment, the frequency of appropriate tensions will increase, but there are limits to this frequency, and to its rate of increase, imposed by the nature of the task. In the extreme case, that is, perfect performance as measured by time-on-target, the inappropriate tensions are insufficient to produce errors, and speed of movement remains at a level demanded by the speed of the target. Thus, the decrease in appropriate tensions will result in a decline in average tension as learning progresses.

Unpaced tasks, such as mirror-drawing and stylus maze learning, impose no such limits to rate of movement and therefore the tendency towards a decline, induced by the reduction in inappropriate tension, might well be offset by the increase in tension resulting from more rapid movements. This interpretation would reconcile the results of this experiment with increases found by Daniel (4), Telford and Swenson (20), and Stroud (18), who tentatively interpreted their data in a similar way.

The observation that tension decreased during OL must be qualified. After the first trial, tension increased and remained higher than, or as high as, the initial level for several trials. This finding is similar to those of Malmo, *et al.* (11), Malmo and Davis (12), Bartoshuk (1, 2), Smith (17), and Surwillo (19), who found increasing gradients during mirror-drawing and tracking tasks lasting for from one to three minutes. They have interpreted the increase as an "arousal" phenomenon, and Bartoshuk (1, 2) hypothesized that the rate of increase is related to motivation. The increase might be interpreted, alternatively, as reflecting the progressive initiation of various responses and is, perhaps, related to what has been termed the acquisition of "set." In the terms of the above analysis, it

would mean that in the early stages of practice the increased frequency of appropriate responses is greater than the decrease in inappropriate ones. Indeed, the frequency of inappropriate responses may not decrease at all until the majority have occurred contiguously with the various task stimuli.

The hypotheses concerning the relations between EMG changes and retroactive inhibition were also, in general, consistent with the data. Inhibition, as measured by time-on-target, resulted from ten trials practice on the reversed task. Previous studies have provided strong support for an explanation of such a decrement in terms of (*a*) the competition between responses established in OL and IL at the time of RL and (*b*) the weakening, during IL, of responses appropriate to OL and RL. In this experiment, the relatively higher muscle tension in RL after ten trials IL, as compared with that after rest, is in agreement with the competition factor; the unlearning factor is supported by the over-all decrease in tension during OL, and by the difference in rate of decline between a group which practised the reversed task as IL and one which practised it as OL.

The effects of the varying amounts of IL on measures at the beginning of RL provide an interesting comparison between performance changes and tension changes. While there were clear differences for both variables between the group receiving ten trials IL and the rest group, the effects of only five trials IL appear to depend on which variable is considered. This smaller amount of interpolated practice had a negligible effect on performance but produced marked changes in tension. The inference might be that small amounts of interfering practice can produce clear evidence in the musculature of competing response tendencies, but the inappropriate responses are not strong enough to disrupt the criterion measure. As the amount of interfering practice is increased, muscular tension increases little, but disruption of performance occurs rather suddenly.

A further indication of the manner in which the two measures are differently influenced by changing conditions is evident from a comparison of the two groups which practised for ten trials on the reversed task, (one as OL and the other as IL). No difference was found between rate of increase in time-on-target. On the other hand, the difference in rate of change of EMG was marked. Again, the suggestion is that interfering response tendencies are evident in the EMG measure but are insufficient to affect the measure of performance.

A comparison of these same groups between EMG levels at the beginning of practice on the reversed task suggests transfer effects. (This experiment was not designed to permit between-groups comparisons of *levels* of tension. However, the data are perhaps suggestive.) EMG was

much higher for the group which practised the task as original learning. If this difference in muscle potential does reflect a difference in muscle tension, it suggests that there are responses eliminated during original learning of the standard task which are irrelevant or inappropriate to both tasks. This would tend to produce positive transfer from the standard task to the reversed, a result which obtained previously (16).

No evidence of an effect due to time of interpolation of the reversed task, on either tension or performance, was observed. There is thus no supporting evidenc for the suggested interaction between residual tensions from IL with appropriate tensions in RL.

There are two results which might appear to argue against a theory involving competition of sets of response tendencies. Originally it was predicted that tension would increase between OL and IL and between IL and RL, owing to interference from response tendencies acquired in previous learning. No clear evidence of the former was found; two groups showed a slight increment and the other a small decrement, and the differences could be attributed to random variability. The difference between level at the end of IL and that at the beginning of RL, for the three groups which practised the reversed task, was in the opposite direction from that predicted.

Two observations might explain these results. First, there is the possibility, noted above, that certain responses, inappropriate to both tasks, are eliminated during practice on either. This would tend to decrease the increment in tension resulting from transferring from one task to the other. A second explanation stems from the rather startling drop in tension evidenced by the rest group between OL and RL. This decrement of 70 microvolts in EMG during an 18¾-minute rest suggests that some process is operating during rest intervals which should affect the other groups to some extent during their shorter rest periods between OL, IL and RL. The suggestion is that this is a quite different process whose effect is opposed to the predicted increase due to response competition.

Summary

This experiment was designed to determine whether EMG might be useful in the explanation of interference phenomena in perceptual motor learning, and to test certain theoretical statements concerning learning and retroactive inhibition.

EMG from the forearm was measured during practice on a Two-Hand Coordinator throughout a retroactive inhibition paradigm. Four groups, of ten subjects each, practised a standard task for fifteen trials, a reversed form of the task for various numbers of trials (0–10), and the standard task again for five trials. A fifth group practised the reversed task without prior learning of the standard task. Systematic changes in EMG were observed, and predictions made from current learning theory were consistent with the data. Specifically, evidence was found of

both experimental extinction and competition of responses, supporting a two-factor theory of retroactive inhibition.

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